The Road-Crossing Safety Ratio as an Index of Reduced Mobility and Risk-taking

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1 Abstract

When a pedestrian suffers a reduction in mobility, do they become less safe when crossing roads, and if so do they adapt their road-crossing behaviour to account for this reduction? An experiment was conducted to investigate the effects of mobility impairment, induced via a leg brace, and self reports of risk-taking on road-crossing safety in a virtual reality environment. A line of 11 vans created 10 randomised gaps of differing temporal size. Three initial distances between the vans were used so gap size was determined by the velocity of each van. There were 60 trials divided into 10 blocks. For the first and last block the participants were unimpaired while for the intervening 8 blocks they were impaired by the brace. Safety, indexed by ratio of the time available to cross to safety relative to the time taken to cross to safety (the *safety ratio*), decreased when the brace was attached and increased when the brace was removed. There was no significant change in the percentage of unsafe crossings (either a collision or being within 0.5 s of being hit) when the brace was either attached or removed, indicating that the reduction in the safety ratio did not necessarily mean the participants were more likely to have an unsafe crossing. There was a decrease in safety when the vans were further apart, indexed by both the safety ratio and unsafe crossings, which replicates previous research. Only limited conclusions could be drawn from the analysis of risk-taking, as although the general trends were in the expected directions the relationships between measures of risk-taking and the performance variables were generally small. Overall, the participants adjusted to their reduced walking speed, surpassing their original unimpaired safety ratios after approximately 3 blocks of impaired trials. The reduction in safety from mobility impairment was only temporary.

2 Introduction

In the 12 months to February 2002 there were 54 pedestrian fatalities on New Zealand roads; in the 12 months to August 2001 there were 934 injuries (LTSA, 2002b). Pedestrians were the third largest group of road users killed or injured after drivers and passengers, making up approximately 8% of the injuries and approximately 12% of the fatalities for their respective time periods (LTSA, 2002b). On urban roads pedestrians fatalities constitute 28% of total fatalities (LTSA, 2002a). When we leave our vehicles we are all pedestrians (LTSA, 2002a).

2.1 Previous Studies

2.1.1 Real-World Studies

Previous studies of road crossing have often investigated the road crossing abilities of children (Connelly, Conaglen, Parsonson, & Isler, 1998; Connelly, Isler, & Parsonson, 1996; Demetre, Lee, Pitcairn, & Grieve, 1992; Lee, Young, & McLaughlin, 1984). A difficulty faced by these studies has been attempting to accurately create the road crossing situation while not putting the participants in any danger. Different tasks have been devised, such as the *pretend road* (Demetre et al., 1992; Lee et al., 1984) where the child crosses a section of footpath the same width as one lane of traffic; the two step task (Demetre et al., 1992) where the child, 60 cm back from the kerb, takes two steps forward when they judge that they would cross the road; the *shout task* (Demetre et al., 1992) where the child calls out ‘now’ when they feel safely able to cross the road; and the *yes/no task* (Connelly et al., 1998; Connelly et al., 1996), where the child says 'yes' until they no longer feel able to safely cross the road at which point they say 'no'.

There are problems associated with each of these techniques. In general the tasks do not require that the participant perform the desired behaviour, i.e. crossing one lane of a road. The two-step and shout tasks model the first part of the actual task, deciding when to begin crossing. However, there is no immediate feedback regarding whether the crossing would have been safe. There is also no chance to re-evaluate mid-crossing, perhaps changing walking speed if it is determined that the current speed is inadequate (Simpson, 2002). Only the pretend road requires the participant to move the actual distance needed to cross a lane of traffic. This provides feedback as the participant is able to see when an approaching vehicle passes their position and could estimate whether they could have safely crossed the lane width or not. One disadvantage is that the optical information available to the participant at the pretend road is different than if they were on the side of the actual road (Simpson, 2002). The yes/no task requires a different judgement to these previous tasks, that of when is it *not* safe to cross opposed to when is it safe to cross. Although they may seem similar a distinction can be made. If humans are generally cautious in their road crossing behaviour then it is likely that there will be a region between what is perceived as safe and what is perceived as unsafe. If the task is to decide when it is safe to cross this region may be judged unsafe. The opposite may be true if they are being asked to decide when it is unsafe. To determine if this is the case the two tasks would need to be compared. Comparisons have been made between the pretend road and two-step, and the pretend road and shout, tasks, but not between safe/unsafe judgements on the yes/no task.

Connelly and colleagues (1998; 1996) found that the children studied tended to use distance to judge if a crossing was safe. This is only appropriate if the vehicles are travelling at a similar velocity. If, not distance provides misinformation about the time-to-arrival (T_a) of a vehicle, as specified by Equation 1.

$$\text{Time-to-arrival} = \text{distance} / \text{velocity} \tag{1}$$

Time-to-arrival has two determinants, distance and velocity. If distance is primarily attended to judgements about safety are likely to be incorrect and could lead to a near miss or collision. Although the Connelly et al. studies only used children, Demetre et al. (1992) found few differences between adults and children regarding unsafe crossings and missed opportunities (not crossing in a suitable gap). It is possible, then, that adults also incorrectly use distance information when making road-crossing decisions.

2.1.2 Virtual Reality Studies

A study was performed at the University of Canterbury to investigate the efficacy of an immersive virtual reality (VR) road crossing simulation (Simpson, Johnston, & Richardson, In Press). This study presented the participants with a series of oncoming vans and they had to choose a safe gap to cross through. There were two trial types. In the first, all the vans maintained the same velocity so differences in T_a were created by varying the distances between the vans. For the second the vans had equal initial distances so differences in T_a were created by varying velocity. Participants were safer when crossing in the equal velocity trials suggesting that they used distance information when make their road crossing decisions. If they had been attending only to T_a information there would have been no difference between the trials. The sample included both children and adults. One of the major advantages of using VR for this type of experiment is that participants are able to physically cross the road in front of vehicles while eliminating any risk of an actual collision.

A subsequent study, simulating “darters” (pedestrians who cross in front of a vehicle when it may be unsafe rather than waiting for an appropriate gap), investigated a forced-choice situation where participants were instructed to cross in front of an oncoming van on every trial (Simpson, 2002; Simpson & Owen, 2002). For these studies the values for the T_a of the vans were individuated based on walking speeds during familiarisation trials. There were three levels of T_a; short, medium, and long. For example, in this figure a short T_a is equivalent across participants although the actual values vary quite considerably between participants, some being longer than one participant’s long T_a. If the values were constant across participants then what was dangerous for one person may not be for another.

The utility of individuation can be demonstrated by examining Harrell & Bereska (1992). This was an observational study investigating 75 individual and group road crossings. Risky crossings were defined as less than 2 s, and cautious crossings were defined as more than 5.6 seconds. Using these criteria Harrell found that older pedestrians had fewer risky crossings than younger pedestrians. Although it is noted that older pedestrians may be less mobile and may also have perceptual difficulties, the gaps they chose compared to their crossing times were not discussed. If they took 1.5 times as long to cross on average, choosing a gap 3 s in size would count as risky but would be recorded as a safe crossing.

Van velocity was varied rather than distance in the Simpson and Owen (2002) experiment. However, a short T_a with a slow velocity would require a close van while a long T_a with a high velocity would require a distant van. With the introduction of individuation the *safety ratio* (Simpson, 2002; Simpson & Owen, 2002) could be calculated so that the short T_a for a van would have equal valence across participants.

The safety ratio is calculated by Equation 2 and will be explained in greater detail in the following section on affordance theory.

$$\text{Safety ratio} = \text{time-to-arrival of the vehicle} / \text{time-to-cross by the person} \qquad (2)$$

In the forced-choice study there were 8 familiarisation trials, 2 in the actual environment and 6 in the virtual environment. Participants were asked to walk at their normal walking speed in the first actual environment trial and the first 5 virtual environment trials, and at a rushed speed in the last trial in each environment. These trials were used to set the times-to-arrival of the vehicle and were also compared to how fast the participant walked in the actual environment, as well as their fastest speed in the experimental trials. It was found that there was only a small difference between the participants rushed actual environment speed and the maximum speed they obtained in the experimental trials, suggesting that they were immersed in the simulation (Simpson, 2002).

These studies revealed that people tend to use distance as well as T_a information to judge how safe it is to cross, a finding comparable with previous real-world work (Connelly et al., 1998; Connelly et al., 1996). It has been proposed that T_a is directly perceivable from the optical event because it is lawfully linked to the event in the environment (i.e., Cavallo & Laurent, 1988; David N. Lee, 1976; McLeod & Ross, 1983; Schiff & Detwiler, 1979; Stewart, Cudworth, & Lishman, 1993; Tresilian, 1997). There is some evidence of this from the VR studies. Owen, Simpson, & Murray (2002) found that participants walked faster when the van was closer, indicating that they were attending to distance information when making their crossing decisions. However, they also walked faster when the T_a of the van was shorter, regardless of the initial distance, suggesting that they also attended to T_a information. There was no interaction between distance and T_a for walking speed, and the effects were of a similar magnitude. This suggests that participants attended to both. However, only T_a information is useful when determining the safety of a crossing. Ideally distance information should not be attended to at all.

2.1.2.1 Simulation Sickness

Simulation sickness (Kennedy, Lane, Berbaum, & Lilienthal, 1993), a condition similar to motion sickness, is a potential problem arising from the use of VR. There have been no problems in any of the previous road-crossing studies using this simulation but this does not mean problems cannot occur. In a separate study investigating control interfaces for the robotic arm on the space shuttles (Lamb, 2002), also conducted in the University of Canterbury Psychology Department's Virtual Reality Laboratory, 6 out of the 45 participants withdrew due to simulation sickness. Participants will be warned about the risks of simulation sickness and will be instructed that if they become uncomfortable they can end the experiment. As a precaution it will also be recommended that they do not drive for an hour following the experiment. The Simulation Sickness Questionnaire (SSQ; Kennedy et al., (1993); see Appendix

A) will be administered pre- and post-test to continue data collection on this condition. The SSQ uses four scales; Nausea (e.g. stomach awareness), Oculomotor (e.g. eyestrain), Disorientation (e.g. vertigo), and a total score. A calibration sample is provided to compare against the scored scales.

2.2 *Affordance Theory*

Affordance theory (Gibson, 1979, p. 127-143) states that an environmental property will support different uses for different individuals with different physical and cognitive properties. An *affordance* can be conceptualised as how an environmental property may be used relative to the *effectivities* of the viewer, or what they are capable of doing. For a circus strongman a phonebook may afford tearing but for most people it affords only reading phone numbers from. Affordances are not necessarily limited to the geometric properties of events but may also relate to the temporal duration of an event; a 4-s gap between two vehicles affords safe crossing within for someone who takes 3 s to cross a road but not for someone who takes 4.5 s. The second person may misperceive the time gap, however, and attempt to cross in a gap that does not afford safe crossing for them. It has been argued that to learn the skills required to perceive this affordance one must act in relation to traffic (Lee et al., 1984).

Warren and Whang (1987) investigated body-scaling in relation to walking through an aperture simulating a doorway. They compared broad shouldered (mean of 48.4 cm) and narrow shouldered (mean of 40.4 cm) males on shoulder rotation when walking through apertures varying between 35 and 90 cm wide. There were two walking speed conditions; normal and fast. Using method-of-limits trials, with gap size either increasing or decreasing, they recorded at which width participants began to rotate their shoulders to pass through the aperture and how many degrees they turned on subsequent trials. The width one larger than the width at which rotation began was referred to as the critical aperture width, i.e. the smallest gap they would walk through without turning. In the normal speed condition they found differences in the mean value for the critical width for the broad and narrow groups (64 and 53 cm respectively), as well as for the number of degrees of shoulder rotation. However, when they took a ratio of aperture width to shoulder width the group differences disappeared. The critical aperture width was approximately 130% of the participant's shoulder width, or a ratio of 1.3. The participants had directly perceived the affordance of the aperture width relative to the critical property of their body. The same trend resulted for the fast walking speed condition except that participants left a greater margin of safety (about 135% versus 130% in the normal speed condition), perhaps demonstrating a greater level of caution (Warren & Whang, 1987).

Temporal gaps between vehicles can be conceptualised in the same way. The time gap between two vehicles can be compared to a person's time-to-cross to produce a measure of safety, the *safety ratio* (see Equation 2). This is a pi ratio i.e., a dimensionless measure (Warren & Whang, 1987). As the ratio decreases to 1 the crossing becomes unsafe. The ratio allows comparison between people with different crossing speeds, or between crossings by the same person at different speeds under different conditions or in different circumstances (e.g. comparing a person's safety when their mobility is unimpaired to when it is impaired; comparing someone rushing for a bus to the same person having a evening walk). Similarly, a safety ratio of 1.2 can indicate crossings of equal safety for someone who walks at 3 m/s or for someone who walks at 6 m/s, if an appropriate gap is chosen.

2.3 Embodiment and Impairment

Hirose and Nishio (2001) investigated the ability of participants to judge the maximum height they could step over and the maximum height they could sit on, both barefoot and wearing *takageta*, traditional Japanese clogs which add 10-cm to a wearer's height. By changing the height of the individual they changed the user's effectivities; they are now 10-cm taller and will be able to step over or sit on heights greater than they could previously. A 10-cm taller chair which before did not afford sitting now will. To describe the act of the individual becoming attuned to their new effectivity the authors used the term *embodiment*.

Another way in which a person's effectivites may change is through impairment. For example, if a person injures a leg then they will be unable to move as quickly. Temporal gaps in traffic that once afforded safe crossing may now be unsafe. Will they adjust their gap choice accordingly, perhaps choosing appropriate gaps that account for their reduced mobility, or will they be unsafe until they adjust their gap choice to their reduced walking speed. This has important safety implications as people will be more likely to be hit if they chose a gap which is too small for their current mobility. If people choose larger gaps then there is no problem, but if there is a learning period where they are at greater risk there is a problem. Whether this period exists and how long it takes for a person to adjust their perceptions of the safety of a gap are important to know in advance. If a period of increased danger exists then people who have recently become mobility impaired can be warned of the increased danger or given sufficient time to adjust.

2.4 *Risk-Taking*

Risk-assessment and risk-taking have been studied in various situations (e.g. sexual behaviours (Hoyle, Fejfar, & Miller, 2000; a literature review), the running of amber traffic lights (Konecni, Ebbeson, & Konecni, 1976), and turning across the path of an oncoming vehicle (Ebbesen, Parker, & Konecni, 1977) as well as driving in general (Donovan, Umlauf, & Salzberg, 1988; Wilson, 1991). It has also been studied in relation to personality factors (e.g. Gullone & Moore, 2000; Hoyle et al., 2000; Levenson, 1990; Vavrik, 1997; Zuckerman & Kuhlman, 2000). Levenson (1990) described differences between three types of risk-takers; antisocial (patients in a drug-treatment facility), prosocial (members of police and fire departments), and adventurous (rock climbers). The antisocial risk-takers scored higher on measures of psychopathology, the adventurous on thrill- and adventure-seeking, while the prosocial scored lower than the other groups on sensation-seeking.

The Risk-Taking Questionnaire (RTQ; see Appendix B) is being developed to assess the level of an individual's adventurous risk-taking using a list of potentially risky activities. Most of these activities were taken from an article on adventure tourism in New Zealand (Bentley, 2001) and other activities were added as they were thought of. The activities were chosen on the basis that a relatively untrained and unskilled person could perform them.

The RTQ consists of three scales; what activities the participant would be willing to do (would not do, might do, would do; 0, 1, 2 respectively (*would do*)), whether the have done the activity or not (0 and 1 for not done and done respectively (*have done*)), and how risky they rate each activity (1-10 with 1 being low risk and 10 being high risk (*risk assessment*)).

Higher levels of risk-taking may be associated with a greater chance of an accident, such as running yellow or red lights (Konecni et al., 1976). The RTQ has be used once previously as a basic evaluation of its discriminating abilities (Owen et al., 2002). Significant positive correlations were found for mean walking speed and for mean reaction time. These suggested that higher levels of risk-taking were associated with walking faster in VR as well as faster reaction times. It is possible, then, that risk-takers will be "safer" in VR, and possibly safer in the real world as well. Risk-takers, when crossing real-world roads, may choose smaller temporal gaps to cross in, but if they cross faster the level of risk may be equivalent or even lower than that of non-risk-takers.

2.5 Hypotheses

The experiment investigated whether the safety of a participant crossing the virtual road changed when their mobility was impaired, and whether a participant's level of risk-taking affected their safety. Previous experiments (Owen et al., 2002; Simpson & Owen, 2002), indicated that participants attended to distance information, as well as T_a information, when making road-crossing decisions. The effect of distance on safety was assessed.

2.5.1 Mobility Impairment

It is predicted that in the impaired condition compared to the unimpaired condition participants will either:

1. recognise that their walking speed has been reduced and will maintain or increase their unimpaired safety ratio, and maintain or decrease their unsafe crossings, or
2. initially suffer a reduction in safety ratio and an increase in unsafe crossings by choosing temporal gaps that are not large enough for their new walking speed, but over trials increase their safety by choosing appropriate gaps.

2.5.2 Distance effect

1. Crossings will be safer when the initial distance between vehicles is small than when it is larger. This is due to the participants using irrelevant distance information (e.g., Owen et al., 2002; Simpson, 2002; Simpson et al.; Simpson & Owen, 2002) as well as relevant T_a information to judge the temporal size of a gap.

2.5.3 Risk-taking

1. Participants with higher risk-taking scores will walk faster in the virtual environment than those with lower scores (Owen et al., 2002).
2. Participants with higher risk-taking scores will either:
    a. be less safe (evidenced by lower safety ratios and more unsafe crossings) than low risk-takers due to crossing in shorter gaps than those with lower risk-taking scores, or
    b. be at least as safe as low risk-takers by choosing gaps appropriate to their faster walking speed.
    c. Be safer than low risk-takers, indicating that they are more competent at assessing gaps appropriate to their crossing speeds.

3 Experiment 1

3.1 Introduction

The first experiment was conducted to test the efficacy of the gap-choice simulation, and also to test a custom built leg brace. The simulation that was used for the Experiment 1 had two types of trials, method of limits, or *increasing,* trials, where the temporal size of the gaps steadily increases and *random* trials, where the temporal gap sizes are randomly ordered (see Section 3.2.3 for further details on these trial types). It is anticipated that the two types of trial will be used for training experiments; the increasing trials for the actual training and the random trials for pre- and post-training evaluations (for more information see Section 4.3.6.2).

3.2 Method.

3.2.1 Participants

Ten participants were recruited for Experiment 1 consisting of friends of the experimenter. Nine were postgraduate students from the University of Canterbury's Department of Psychology and the tenth was self-employed. Their VR experience varied; some had been involved in previous road crossing research while others had not. They were tested initially in the mobility unimpaired condition and were recalled after the construction of the leg brace to be tested in the mobility impaired condition (see sections 3.2.2.3 and 3.2.4 for further details on the leg brace). The same 10 participants were recalled as there had been no apparent learning effect across trials, indicated by the lack of any block main or interaction effects for the dependent variables (see Section 3.3)

3.2.2 Materials and Apparatus

3.2.2.1 The Actual Environment

The Virtual Reality Laboratory is 805 cm wide by 816.5 cm long, and is approximately 295 cm high. The base of the box holding the transmitter is 195 cm above the floor.

3.2.2.2 The Virtual Environment

The virtual environment consisted of a straight section of road having one lane each way. The centre line of the road consisted of a broken white line dividing the road into two 3-m lanes. There was a continuous white edge line along both sides of the road. A tree was located directly behind the participant's starting position and a street light was located directly opposite. See Figure 1. for a bird's eye view of the environment.

In the crossing situation the participant encountered a line of 11 oncoming vans of different colours. The vans were centred in the lane and the far edge of each van was about 0.55 m from the centre of the road. The participant had no virtual representation, i.e. no virtual body such as hands and feet.

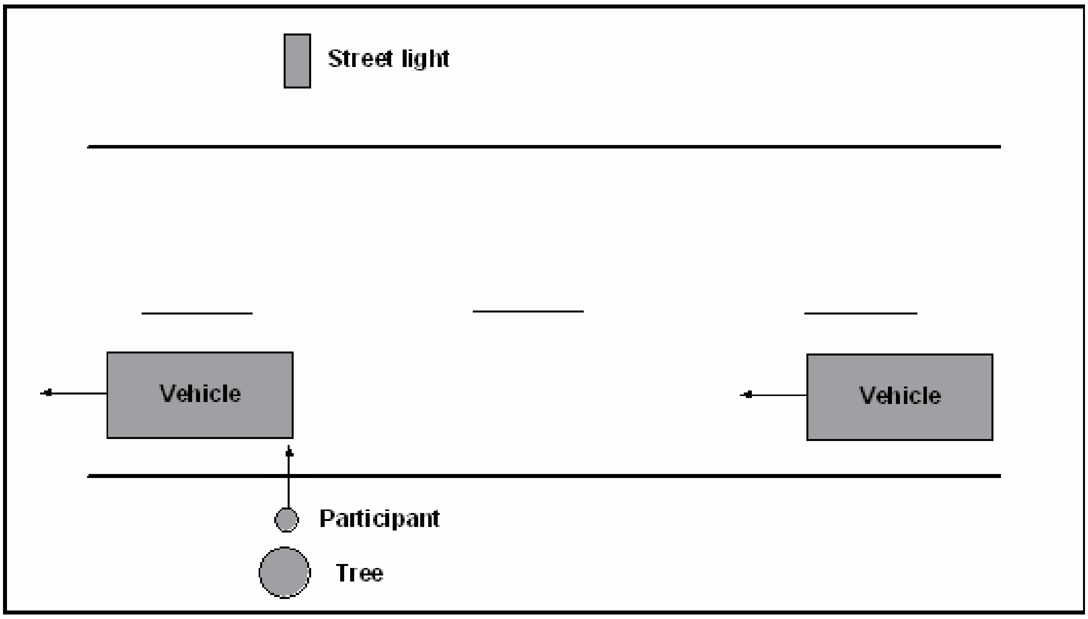

Figure 1. A bird's eye view of the central portion of the virtual environment. The participant is shown at the starting position at the side of the road with one vehicle just passed and another approaching their intended crossing path.

3.2.2.3 Hardware

The virtual environment was generated by an 500 MHz Pentium MMX™ PC with 128-Mb of RAM and a 32-Mb GeForce2 MX 3D graphics accelerator card. The virtual environment was viewed through a Virtual Research Systems V8 Head Mounted Display (HMD) containing two full-colour 3.3-cm x 640- x 480-pixel active matrix liquid crystal displays with a refresh rate of 60 frames per second, presenting a 48-degree horizontal and 60-degree diagonal field of view to each eye. Although the system had the potential to produce stereoscopic images, the same image was presented to each eye (synoptic images) due to technical difficulties (the programmer had difficulties configuring the graphics card to produce stereoscopic images and lacked the time to resolve the problem; Gordon Simpson (2003), personal communication). The system included a 6-degree-of-freedom head tracker (Ascension Technology Flock of Birds with extended range transmitter) with an orientation and position sample rate of 60 times per second. The position of the participant was recorded from a receiver on the top of the HMD. Movements, of either the head or the entire body, changed the *camera viewpoint*, i.e. what the participant sees. The camera locus was used to determine whether an individual crossing is unsafe (see Section 3.2.3)

For this experiment a leg brace was constructed. It consisted of two aluminium plates, each covered in foam rubber and attached together on either side of the leg by four straps secured by Velcro. Each brace section was approximately 65-cm long by 15-cm wide. The length of the Velcro straps varied depending on where they were to be attached to the leg, and the brace could be fitted to almost all leg sizes, but it did not fit very small or very large legs properly.

3.2.3 Design

The experiment consisted of 32 trials. The first 2 trials were conducted in the actual environment with the helmet resting on the head without lowering the visor over the participant's eyes. This enabled the participant's walking speed to be recorded while still allowing them to see the actual environment. The following 30 trials were in the virtual environment with the first 6 being familiarisation trials.

Trial 1: The participant is asked to cross the laboratory room at a normal walking speed (in the actual environment),

Trial 2: The participant is asked to cross the laboratory room as if they are in a rush (in the actual environment),

Trials 3-5: The participant is asked to walk towards the street light at a normal walking speed in the first 3 virtual environment familiarisation trials,

Trials 6-8: The participant is asked to walk towards the street light as if they are in a rush in the last 3 virtual environment familiarisation trials,

Trials 9-32: In the remaining virtual environment experimental trials the participant is asked to cross the road when they feel it is safe.

There was no traffic in the familiarisation trials. When the participant reached the centre of the road, a pre-recorded message presented via the HMD headphones instructed them to turn around and return to the tree. This message occurred when they had. These trials were used to familiarise the participant with moving in the virtual environment and to gain measures of the participant's normal and rushed walking speeds in each environment. The virtual trials were also used to calibrate the experimental trials (see below).

The participant's task was to safely cross one lane of the virtual road (see Appendix C for the full instructions). Eleven vans approached from their right creating 10 gaps of differing size (the first van was there to create the first gap; it had a constant T_a of 1.5 s and is not included in further discussions as only the other 10 vans are manipulated). The participant had to choose when and how fast to cross the lane to avoid being hit. They were asked to walk at whatever speed seemed necessary. It was stressed in both the familiarisation and experimental trials that they should keep walking until they heard the message instructing them to return. If they stopped partway through a trial, measures of walking speed could not be recorded and, if they began walking again, some of the recorded measures may be inaccurate. Although not explicitly stated it was implied that they were to cross before all the vans had passed since they were told to cross in a gap they perceived as safe. The reason for this was that only trials in which the participant crossed before all the vans passed could be used, but this was not explicitly stated as it was desirable to observe the participant crossing as naturally as possible. Stating that they had to cross before all the vans had passed might have affected their normal road crossing behaviour. In the first gap-choice road-crossing experiment there were a number of participants who waited until all of the vans had passed before they crossed the road (Simpson et al., In Press), and there have been cautious crossings in the forced-choice experiments as well (Owen et al., 2002; Simpson, 2002). The reluctance of a participant to cross, even though they are in no physical danger, suggests that they are immersed in the simulation and are probably behaving in a fashion similar to the way they would in the real world. It was deemed of greater importance to allow the participants to behave in a way that more closely matches their real world behaviour than to focus on minimising unusable data trials.

The shortest time-to-cross from the virtual environment trials was used to individuate the trials. The time-to-cross is measured from 0.5m in front of the starting position at the roadside until the participant reaches a safe point on the centreline of the road (the 0.5-m distance was assigned arbitrarily to determine when the participant has begun to cross the road rather than indicating a position change which could be due to body sway). This measure is used to calculate time-to-arrival by Equation 4:

$$\text{Time-to-arrival} = \text{shortest time-to-cross in training}*(1+(T_a\text{Factor}*(\text{VanNo}-1))) \quad (4)$$

The T_aFactor is a value that determines the increase in T_a for each subsequent van. For example, if the value is set at 0.15 and the shortest time to cross in training was 2 seconds then the first gap will be 2 s, the second 2.3 s, the third 2.6 s and so on. The ordinal number of a van for gap size is not necessarily the number that it will appear in a trial. For an increasing trial it will be, but if the vans are randomly order it will not.

Data was first collected on the 10 participants in the unimpaired condition. Once the leg brace had been constructed they were recalled and tested in the impaired condition. Their times-to-arrival for the impaired trials were calibrated on their unimpaired walking speeds to ensure that each participant was facing the same 10 gaps while impaired as they had initially. The brace was fitted both to the sides of the leg and also to the back and front of the leg to investigate whether there were any differences in impairment based on the position of the brace. If there had been a difference data from the two conditions would have been analysed separately, otherwise the data would be pooled.

In the experimental trials all the vans began the same distance apart (see below). Velocity was varied to create the different times-to-arrival based on Equation 5:

$$\text{Van velocity} = \text{initial distance} / \text{time-to-arrival} \qquad (5)$$

Initial distance consisted of three levels; 40, 50, and 60 m. As an example a graph of the 10 van velocities over the three levels of initial distance, using a shortest crossing time of 2 s, is shown in Figure 2.

For Experiment 1 there were two types of trial: increasing and random. In an increasing trial the times-to-arrival of the gaps steadily increases whereas in a random trial they may occur in any order.

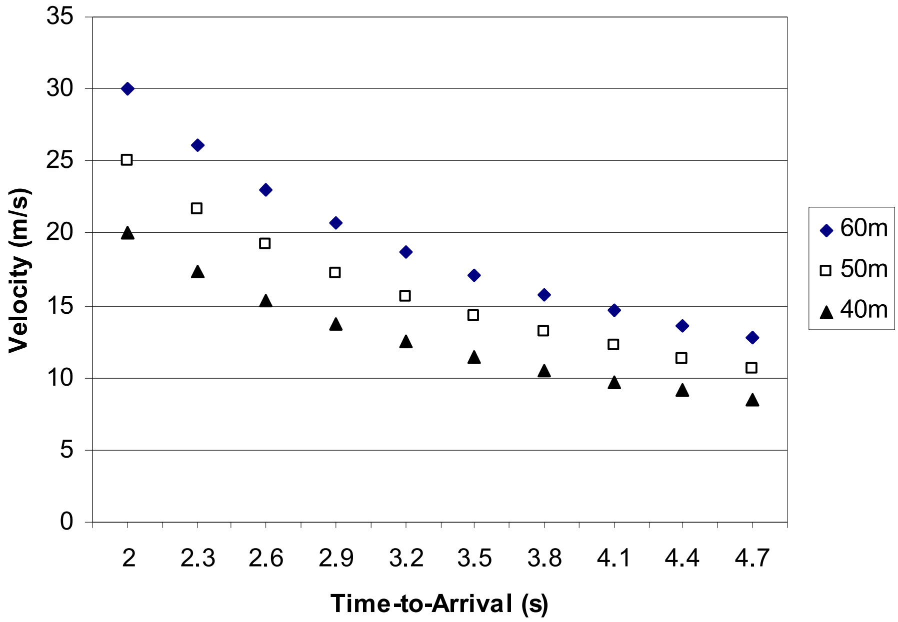

Figure 2. The values of velocities for the three initial distances, given a shortest crossing time of 2 s and a T_aFactor of .15.

There were 4 blocks of 6 unique trials. The unique trials consisted of combinations of the 3 distances and the 2 trial types. See Table 1 for a summary of the independent variables. The five dependent variables for Experiment 1 are shown in Table 2.

The safety ratio used here differs from the ratio described earlier (p. 6). Rather than being calculated on the total available crossing time between vans, it is calculated on the time available from when the participant begins moving (see Equation 6). In this way it accounts for the time taken to make a decision to cross or not to cross. A participant who waited longer had less of the gap available in which to cross in if they decided to cross.

$$\text{safety ratio} = \text{available crossing time} / \text{time to cross to the centre of the road} \qquad (6)$$

A crossing is deemed unsafe if the participant is hit or is within 0.5s of being hit. The participant is considered to be hit if their camera viewpoint fell within the length and width (but not height) of the outer bounds of the van's position. Walking Speed is taken as the average speed over 2.5 m (3 m less the 0.5 m to avoid body sway being mistaken

Table 1. Independent variables for Experiment 1.

Variable	**Description**	**Number of levels**	**Levels**	**Unit**
Mobility Condition	Whether the participants mobility was impaired or not.	2	Impaired, unimpaired	-
Initial Distance Between Vans	The distance between the rear of a van as it passes the participant and the front of the next van	3	40, 50, 60	m
Trial Type	Whether the times-to-arrival of the vans are increasing or randomly allocated across the 10 gaps	2	Increasing, random	-
Block	The four repetitions of the six unique trials	4	1st, 2nd, 3rd, 4th	-

Table 2. Dependent variables for Experiment 1.

Variable	**Description**	**Unit**
Safety Ratio	The ratio of the available crossing time from when the participant begins to move to the time taken to cross	-
Unsafe Crossings	Crossings in which the participant was either hit or within .5 s of being hit	-
Walking Speed	The speed with which the participant crossed from 0.5-m to the far edge of the lane	m/s
Percentage of Available Gap Used	The percentage of the available gap used by the participant	-
Gap Number Chosen	The ordinal number of the van that the participant crosses in front of: 1st, 2nd, etc.	-

for a position change). Percentage of Gap indexes how much of the gap was utilised by the participant (Equation 7):

$$\text{Percentage of Gap} = \frac{T_a \text{ of the van when the participant begins to cross}}{\text{total } T_a \text{ of the van}} * 100 \qquad (7)$$

A value of 1 indicates that the participant began crossing as soon as the previous van passed their position. A value of .5 indicates that they waited for half of the T_a of the van before crossing, i.e. if the van had a T_a of 3 s they would have waited 1.5 s before crossing. Gap Number Chosen refers to the ordinal number of the gap the participant chose for a specific trial and was expressed as the average gap chosen in the analysis. A higher number indicates the participant waited longer before crossing. It can only be used as an indication of risk for an increasing trial. A distinction will be made between temporally ordered gap number, i.e. gap number chosen, and size ordered gap number. if the gaps were ranked by times-to-arrival 1 would be the shortest and 10 would be the longest. For the increasing trials these two numbers are the same but for a random trial they will almost always be different. In general only the temporally ordered gap number will be used but in one instance (Section 3.3.4) a distinction is required. Table 3 shows example values for the size ordered gaps, both in the appropriate gap number and T_a value, for an increasing and a random trial. The T_a values are taken from Figure 2.

3.2.4 Procedure

Participants were informed that they could withdraw from the experiment at any stage. The participants were positioned on a red strip of tape on the floor slightly to the right of the transmitter. They could use this strip as a way of repositioning themselves at the beginning of

Table 3. The size ordered gap numbers for an increasing and a random trial. Temporal gap order refers to the order in which the participant encounters the gaps.

Temporal Gap Order	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Size Ordered Gap Number: Increasing Trial	1	2	3	4	5	6	7	8	9	10
Time-to-arrival (s): Increasing Trial	2	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.7
Size Ordered Gap Number: Random Trial	8	10	6	3	7	9	4	1	2	5
Time-to-arrival (s): Random Trial	4.1	4.7	3.5	2.6	3.8	4.4	2.9	2	2.3	3.2

each new trial (they were instructed to raise the HMD slightly to see the floor once they had returned to the starting point). They were instructed to walk towards the street light and, on the return, to walk towards the tree (see Figure 1). Equipment and furniture in the room were positioned to minimise the risk of collision. At the end of each trial a black screen with white text instructed the participant to prepare for the next trial, and there was also a verbal message with the same purpose. The number of the trial was also presented concurrently, and as they had been verbally informed of how many trials there would be participants were aware of how far through the experiment they were.

For the unimpaired trials, participants were tested for four blocks of trials. There were also four blocks of impaired trials. For two of the impaired blocks the leg brace was positioned along the side of the leg, and for the other two it was positioned front and back. Half of the participants wore it in the first position initially and half wore it in the second. After two blocks the position was changed. Participants were counterbalanced for how the leg brace was attached initially. After two blocks of trials the brace was moved into the other position.

3.3 Results and Discussion

The main purpose of Experiment 1 was to determine whether there was a difference between the increasing and random-gap trial types, and whether the leg brace reduced mobility. Previous research using the forced-choice road-crossing simulation (Owen et al., 2002; Simpson, 2002) found effects of block order so it was predicted that this would occur with this experiment. A block effect would indicate the need to use a separate group of participants to test the leg brace. As there was no block main effect or interactions it was decided that the original 10 participants could be used again. Unfortunately, due to the previous prediction of a block effect, the order that the participants completed the unimpaired section of the experiment had not been recorded. This means that for the analysis they were considered to be two independent groups, a between-participants rather than within-participant comparison. This increases the risk of a Type 1 error as the assumption of independence has been violated. However, the overall means between unimpaired and impaired can still be compared; these would be the same as a for within-participant analysis. Some caution must be taken regarding the other effects, but in general these replicate the effects from the unimpaired trials.

There were four missing data points, two due to cautious crossings and two from the experiment being ended by the experimenter, most likely due to a participant not crossing at all. These data points were all in the unimpaired blocks. The two cautious crossings came from the same participant whereas the other two were from different individuals. The data were replaced by mean substitution using the data from the other participants for that specific trial. No unique trial (i.e. the 40-m increasing trial in the first block) had more than one missing data point.

Before the data were combined, an analysis was conducted on the impaired data to investigate whether the position of the leg brace, front or side, had any effect. There were no significant effects for brace position, so the data for the two positions were pooled and treated as replications.

Analysis was by a 4-way (2 condition x 4 block x 3 initial distance x 2 type of trial) ANOVA with repeated measures on the last three factors. After the analyses there will be a general discussion (Section 3.3.6). Effect sizes and power analyses for the main effects are presented in Appendix F.

3.3.1 Safety Ratio

There was no difference in safety ratio between the unimpaired and impaired conditions (means 1.03 and 1.02 respectively). There were significant main effects for initial distance between vans (means 1.28, 1.02, .77 for 40, 50, and 60 m respectively; replicating the effect of Owen et al, 2002), $F(2,36) = 59.28$, $p < .05$, type of trial (0.95 and 1.10 for increasing and random respectively), $F(1,18) = 4.58$, $p < .05$, and an interaction between the two, $F(2,36) = 7.22$, $p < .05$. As Figure 3 shows there was very little difference between the two trial types at the 40-m distance, but there is a difference at the 50- and 60-m distances with random trials being safer than increasing.

The Trial Type main effect suggests that people are sensitive to the difference between the two trial types. The difference between the two types of trial becomes more interesting when examined through the interaction. At the 40-m initial distance there is almost no difference

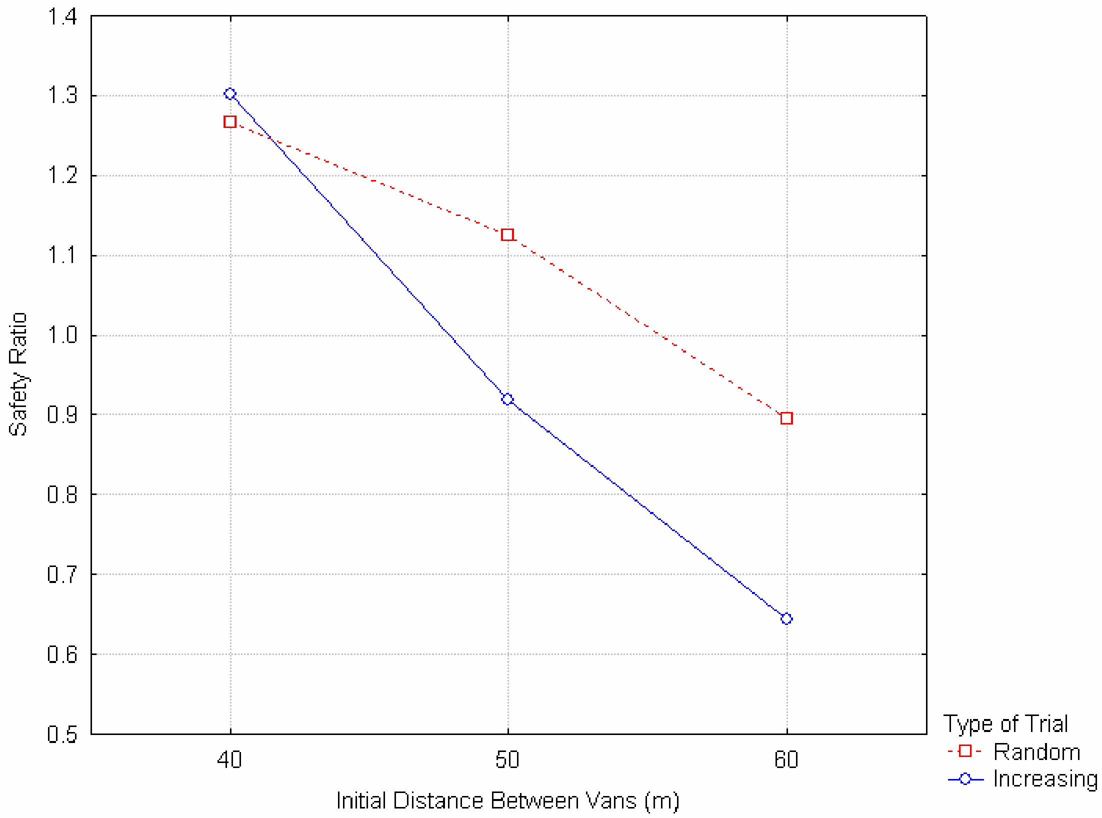

Figure 3. Safety ratio as a function of initial distance between vans and type of trial.

between the two types of trial. This suggests that when the initial distance is short this information, rather than whether the temporal gap sizes are increasing or are occurring randomly, is attended to. However, the further apart the vans are initially the greater the difference between the two types. Some attention may be paid to the trial type when there is the perception of more time to wait due to a greater initial distance. See Section 3.3.3 for further discussion.

3.3.2 Walking Speed

The mean for the impaired trials was lower than for the unimpaired trials (1.6 and 1.77 m/s respectively) although this difference was not significant, $p = .25$. The effect of type of trial was significant, $F(1,18) = 6.11$, $p < .05$, participants walking faster in the increasing trials than in the random trials (1.71 and 1.65 m/s respectively). The significant block-by-mobility condition interaction is shown in Figure 4, $F(3,54) = 3.04$, $p < .05$. Visually it appears that this interaction is coming primarily from the second block of the impaired trials. There is a difference of at least 0.17 m/s between the unimpaired and impaired means for the other three blocks but for Block 2 this difference is 0.018 m/s.

Although the leg brace did reduce walking speed, it did not do so significantly. The lack of a significant difference may be attributable to low power, power = .15, and the block-by-condition interaction. Excluding Block 2, the means for the unimpaired and impaired groups are 1.77 and 1.55 m/s respectively, a difference greater than 0.2 m/s. A decrease of 0.2 m/s means it would take 0.5 s longer to cross the 2.5 m recorded width of lane, potentially turning a safe crossing into a close call (being within 0.5 s of being hit). Another problem may be due to using the same participants twice. An earlier experiment (Owen et al., 2002) suggests that walking speeds increase over trials as participants spend longer in the simulation. The baseline walking speed, then, may have been higher than would be expected for naïve participants, and there does appear to be a slight increase in speed from the third to the forth unimpaired block (see Figure 4). This is supported by a comparison of the mean smallest temporal gap size in each condition (1.61 s and 1.50 s for unimpaired and impaired respectively), although this is only a small difference. Finally, the design of the brace may have caused problems. The aluminium pieces were quite wide meaning that the straps, rather than wrapping tightly around the leg, had contact primarily with the brace. This made tightening the brace more difficult than was desirable and resulted in

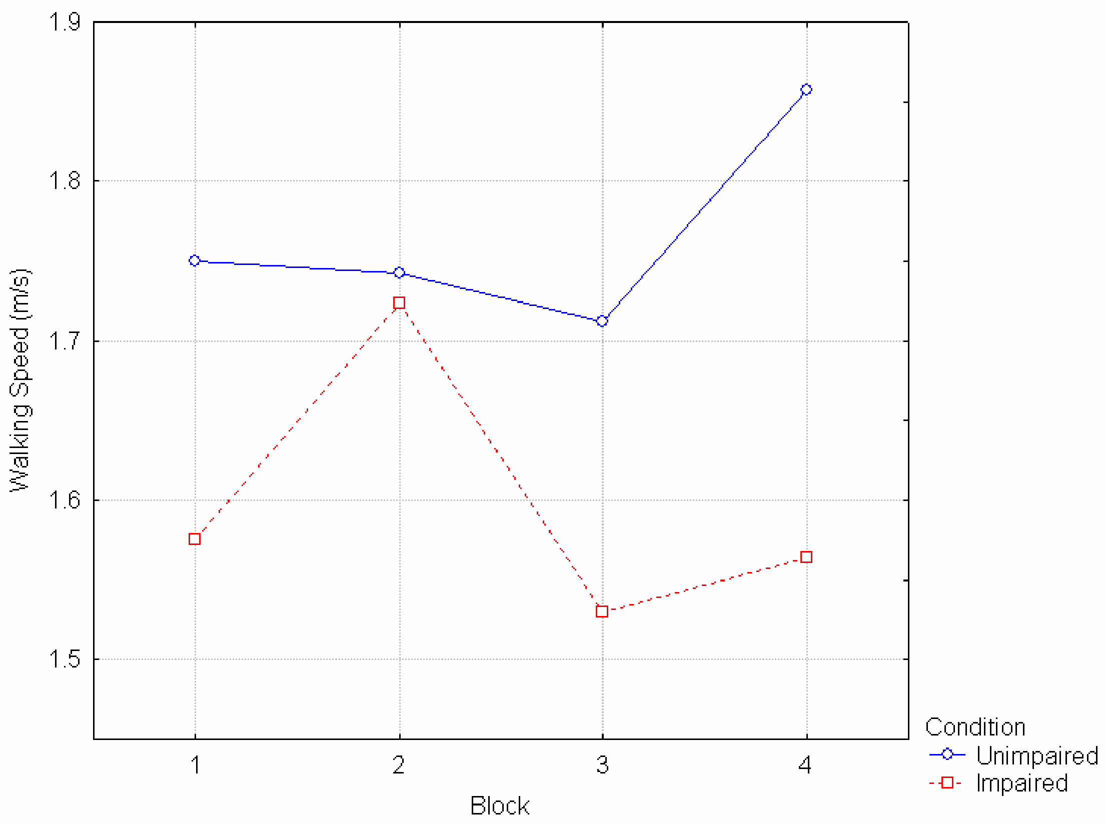

Figure 4. Walking speed as a function of block and mobility condition.

the brace becoming loose on a number of occasions. If loose the brace may have failed to impair walking speed as much as was hoped.

While the safety ratio decreased as initial distance increased, replicating the finding from Owen et al (2002), there was no equivalent effect on the participants' walking speeds. Previously (Owen et al., 2002), the decrease in safety could be linked to a decrease in walking speed. This is fairly intuitive as the time-to-cross the lane is used as the denominator for the safety ratio (see Equation 2), and the lane width (2.5 m) is divided by the time-to-cross the lane to derive a participant's walking speed for a particular trial. A shorter time-to-cross the lane will result in an increase in both the safety ratio and walking speed. If the walking speed component of the safety ratio is not changing then the other component, the T_a of the van as they begin to cross, must be. This will be discussed further in Sections 3.3.3 and 3.3.6.

3.3.3 Percentage of the Available Gap Used

There was almost no difference between the impaired and unimpaired trials for the percentage of available gap used, $p = .12$, although the mean percentage of the gap used was slightly greater for the impaired trials than unimpaired trials (69% and 67% respectively). There were main effects for initial distance between vans (means of 76%, 68%, 59% for 40, 50, and 60 m initial distances respectively), $F(2,36) = 88.56$, $p < .05$, and for type of trial (means of 65% and 71% for increasing and random trials respectively), $F(1,18) = 13.84$, $p < .05$, with a significant interaction between the two, $F(2,36) = 7.58$, $p < .05$, shown in Figure 5. As with the safety ratio there was very little difference between the trial types at the 40-m initial distance but there was for the 50- and 60-m distances.

The Initial Distance effect suggests that the participants are attending to distance information as well as T_a information. As initial distance increases participants are using less of the available gap. This is similar to the equivalent effect on the safety ratio. It is possible that the decrease in safety ratio is not linked to walking speed, as has been found earlier, but to the percentage of the available gap used. For the same sized initial gap, say 3 s, and with no change in walking speed, the safety ratio will be lower if the participant waits longer before crossing. Waiting for 1 s would leave 2 s of the gap to cross in, whereas waiting for 0.5 s leaves 2.5 s to cross. With a walking speed of 2 m/s the first case would result in a collision while the second would be a near miss. This highlights a difference between the forced-choice and gap-choice simulations. In

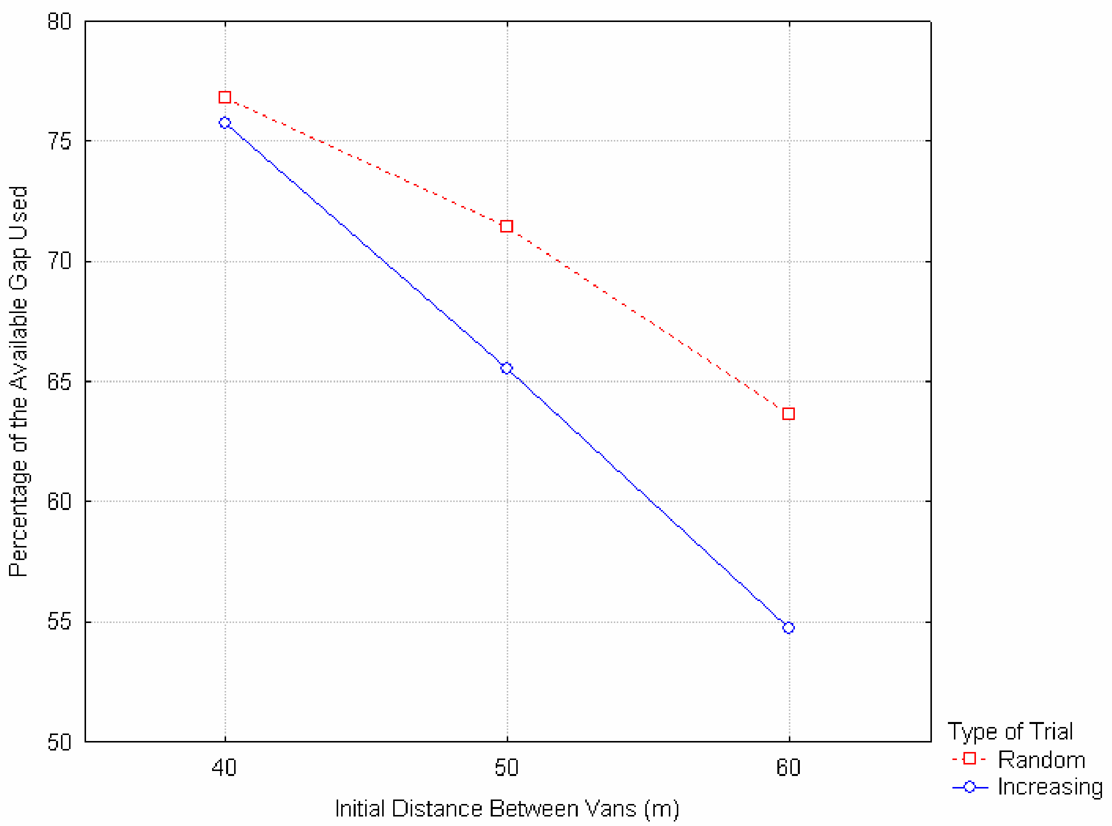

Figure 5. Percentage of the available gap used as a function of the interaction of initial distance between vans and type of trial

the former how fast you cross the road is important, as you have to cross regardless of where the van is, whereas in the gap-choice participants can chose when to cross rather than how fast to cross.

The Trial Type main effect again indicates that participants are sensitive to the difference between the increasing and random trials. From the interaction it can be inferred that they are only sensitive to the difference when there is the perception of a longer T_a, i.e. when the initial distance is medium (50 m) or long (60 m). When the initial distance is 40 m there is no visible difference, as with the safety ratio. One possible explanation for the interaction effect is that participants are willing to spend longer waiting before crossing if they perceive that they have more time to wait (i.e. the assumption that because the initial distance is larger the gap must be longer) and if they perceive the increase in temporal gap size. With the random trials lacking any regularity in regards to prediction of the size of the next gap from the previous gap, participants may feel a need to wait less time once the preceding van has passed. With the increasing gaps some of the decision about whether to cross in the following gap can be based on the previous gap. The participants may be attending to the fact that the gaps are increasing, but may not detect the magnitude of the increase. The increase in waiting time may be linked to a desire to confirm that the gap is larger, and then to cross if it is. The relationship of this variable to the safety ratio indicates that although they may feel that the gap is safe often it is not, probably due to the waiting time. At the 60-m initial distance participants were using approximately 55% of the available gap in the increasing trials compared to almost 65% in the random trials.

3.3.4 Gap Number Chosen

The main effect for impairment condition was not significant, $p = .35$, although the mean gap number chosen was marginally later for the impaired trials than the unimpaired trials (4.92 and 4.39 respectively). There were significant main effects for both initial distance between vans, $F(2,36) = 36.85$, $p < .05$, and type of trial, $F(1,18) = 33.09$, $p < .05$. The mean gap numbers chosen were 5.68, 4.68, and 3.60 for 40-, 50-, and 60-m initial distances respectively. The mean gap numbers chosen were 4.09 and 5.22 for random and increasing respectively. These main effects are shown in Figure 6. The interaction was not significant. There was also a significant 3-way interaction of trial block, initial distance between vehicles, and type of trial, $F(6,108) = 2.407$, $p < .05$ (see Figure 7).

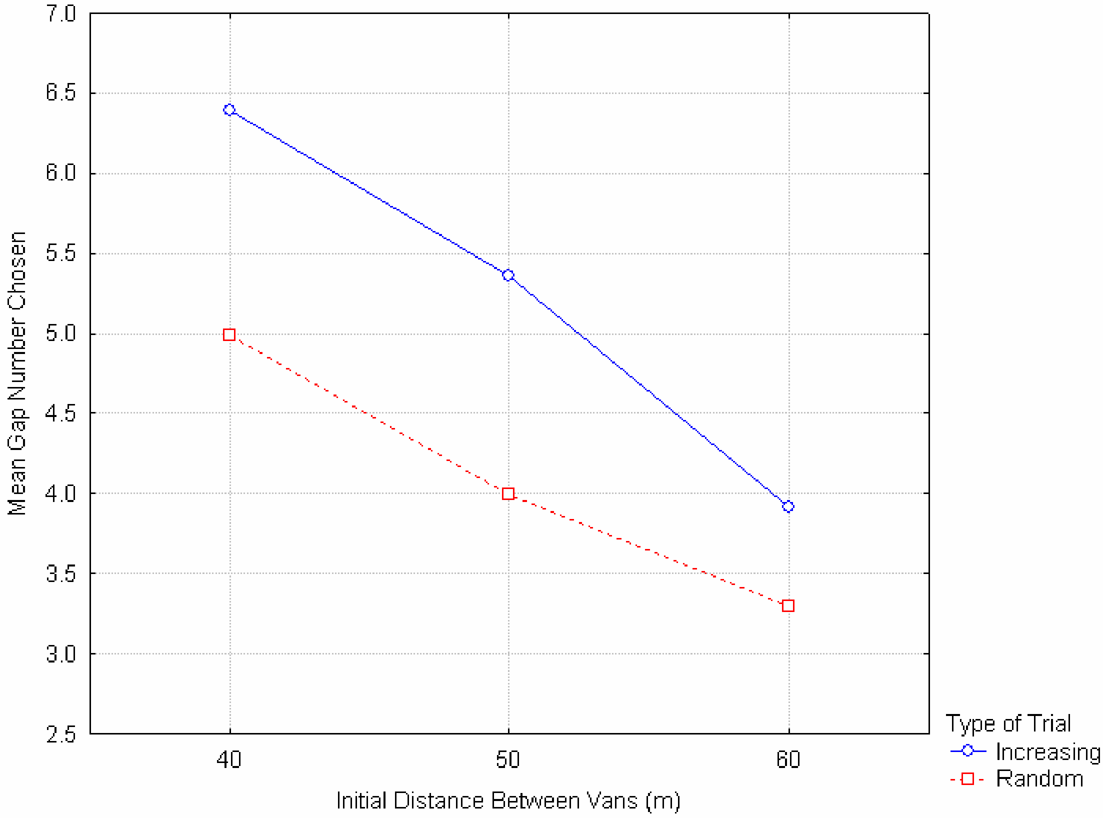

Figure 6. Mean gap number chosen as a function of initial distance between vans and type of trial.

It appears that, over blocks, the effect of initial distance increases for the increasing trials (i.e. the lines diverge) but decreases for the random trials (i.e. the lines converge). This trend was also apparent in the equivalent, but non-significant, interactions for safety ratio and the percentage of the gap used. The effect will be discussed further in Section 3.3.6

There is again a strong initial distance effect. The larger the initial distance the sooner the participants crossed. The main effect of trial type may relate to when the safe gaps occur. Participants crossed later in the increasing trials than they did in the random trials. For the

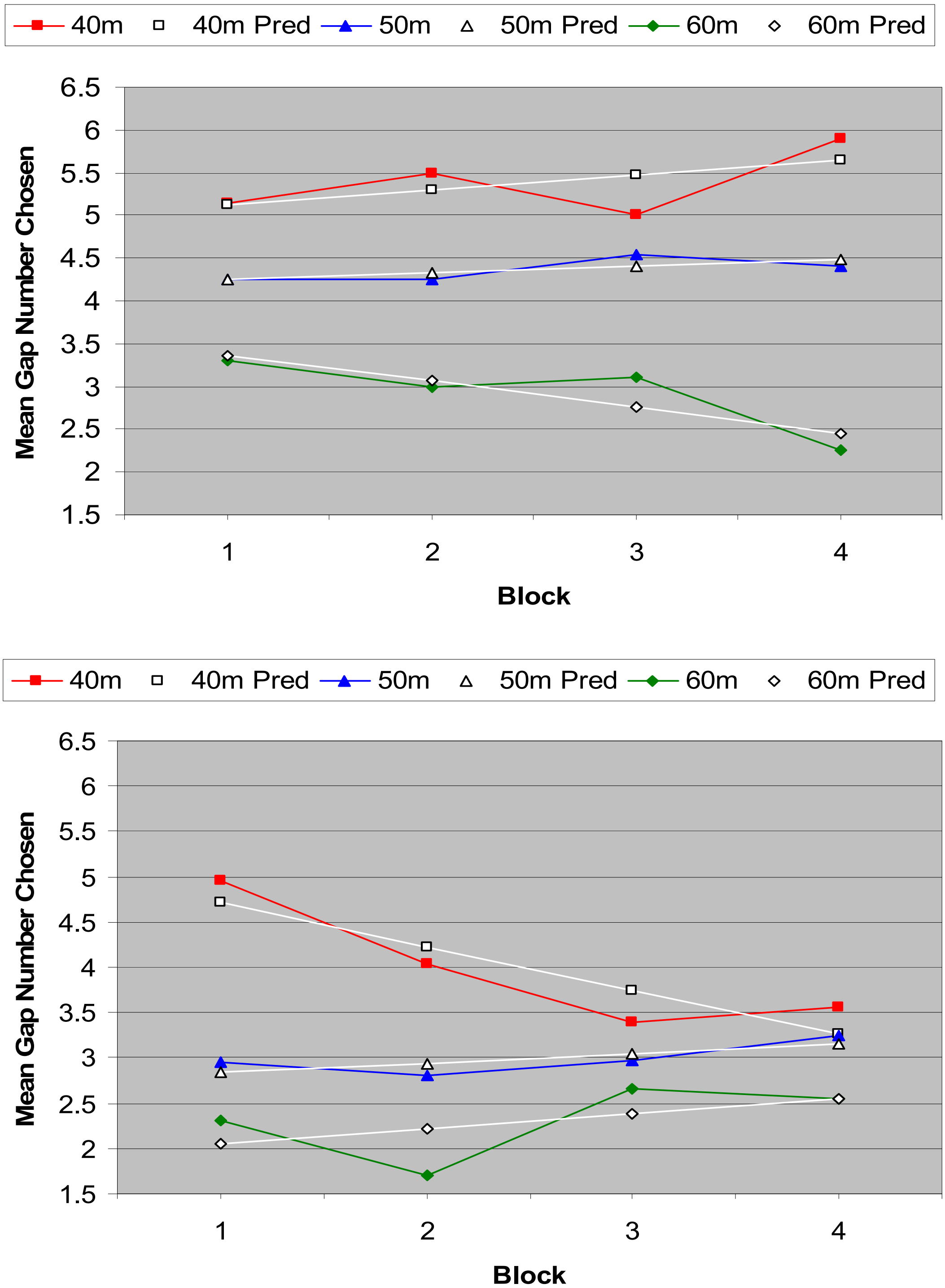

Figure 7. Gap number chosen by block, and initial distance between vans for the increasing trials (diverging lines; top panel) and random trials (converging lines; bottom panel). *Pred.* indicates the linear regression fit for each level of initial distance over blocks.

increasing trials each gap is presented in the same position, so that Gap 4 affords the same safety for both the first and last encounter, assuming a constant walking speed. For the random trials it is possible that Gap 4 will be the largest gap or the smallest gap, or any gap in between. Any difference may be attributable to larger gaps occurring earlier in the trial for the random trials. It is also possible that the information about the size of the following gap from the previous gap (i.e. decreasing van velocities leading to increasing times-to-arrival for the increasing trials), which may have led participants to wait for less time before crossing, also affected when they crossed. If they perceived the gap as safe they crossed. What seems more likely is that it is a combination of the two (i.e. they correctly perceived that the earlier gaps were safe). The safety ratio data shows that participants were safer in the random trials, so it is unlikely that the early gaps in a random trial were less safe. If they were less safe there would have been more unsafe crossings in the random trials. This was tested with a single sample t-test using the size-ordered gap numbers (e.g. for a random trial the third gap that occurs may be the sixth shortest when the gaps are ranked from smallest to largest; for an increasing trial they would be the same; refer to Table 3). The size-ordered gap numbers for the random trials were averaged over the first 5 gaps, in the temporal order in which they occurred, for each participant. The first 5 gaps were chosen, as in general participants crossed before the fifth gap (see Figure 8). The means across participants were compared to the equivalent mean for increasing trials, which was a constant number (3). The random trials had a mean size-ordered gap of 5.55, which is close to the average across all 10 gaps (5.5). This difference was significant, $t(19) = 32.23$, $p < .05$. The early gaps were significantly larger in the random trials than in the increasing trials. The longer waiting times for the increasing trials would also have reduced the overall safety of the gap.

3.3.5 Unsafe Crossings

Due to certain trials (16 and 20 for the unimpaired condition) lacking any unsafe crossings the data could not be analysed statistically using the repeated measures design. The following analysis is based on visually comparing means for the different conditions. There was only a small differences between the impaired and unimpaired trials, an overall mean difference of 0.4%. As the initial distance between vans increased so did the percentage of unsafe crossings (23%, 35%, and 62% for 40, 50, and 60 m respectively). There was also a greater percentage of unsafe crossings in the increasing trials than in the random trials (49% and 31% for increasing and random respectively). Figure 8 shows the interaction between the variables. There was a small decrease in the percentage of unsafe crossings in the last two blocks compared to the first two (45%, 45%, 33%, and 36% for Blocks 1, 2, 3, and 4 respectively). These results are similar to those found for the safety ratio, a decrease in safety ratio resulting in an increase in the percentage of unsafe crossings.

3.3.6 General Discussion

The analysis of the unimpaired trials demonstrated the efficacy of the simulation. Significant effects were detected for both the initial distance between vans and for the type of trial using a small sample size (N = 10). The effect of distance replicates that of Owen et al. (2002). The participants may have been erroneously attending to distance information rather than T_a information. In the previous study (Owen et al., 2002) the decrease in safety ratio could be attributed to a decrease in walking speed as distance increased. In this case, however, the initial distance between vans had no effect on walking speed. The reduction in safety ratio must be

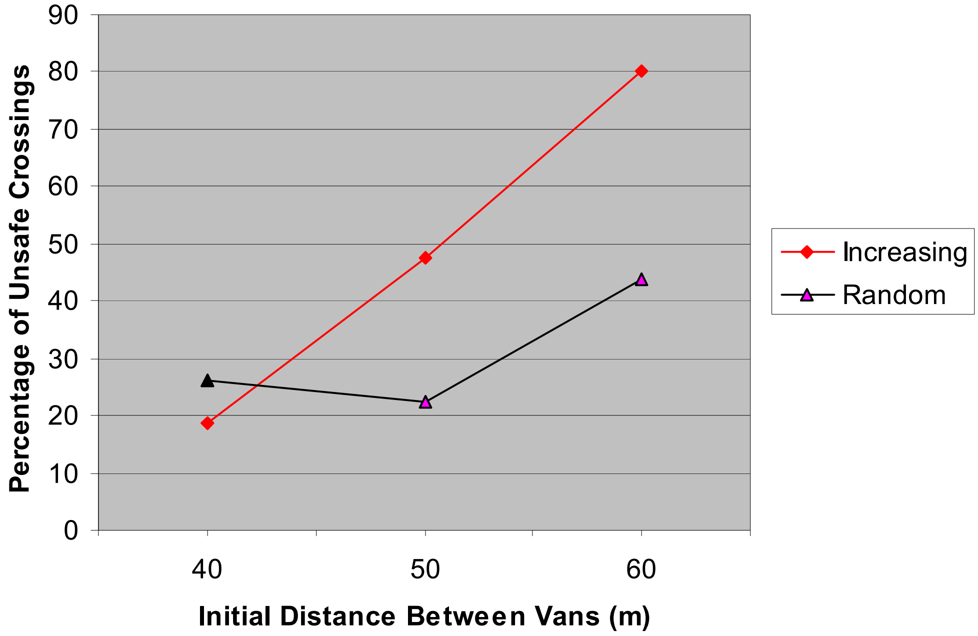

Figure 8. The percentage of unsafe crossings as a function of the type of trial and initial distance between vans.

linked to a different change in the behaviour of the participants. It was found that the percentage of the available gap used did exhibit an initial distance effect. The later a participant crosses in a gap the less time they have to cross safely, so it is likely the effect distance has on the safety ratio occurs due to participants using less of the gap when distance is greater.

The results between impairment conditions using the full data, however, were somewhat disappointing. Although there were differences in the dependent variable means and in the expected directions between the two conditions, none were significant. It would appear that some of the reason for this relates to the construction of the leg brace, and possibly to using the same participants twice. In hindsight it may have been prudent to use a second group of 10 to test the brace. Although there were no block effects it is possible that familiarity of the participants with the virtual environment affected their walking speeds in the impaired trials.

However, being that the differences were all in the expected directions, if only marginally so, it was decided to continue with Experiment 2.

The significant three-way interaction for gap number chosen indicated that over blocks the effect of initial distance was diverging for the increasing trials but converging for the random trials. This trend was also evident for the safety ratio and gap number chosen, although these interactions were not significant. If this effect is robust it will require further investigation as it is envisioned that the two types of trial will be used for training focused on reducing or eliminating participants' use of distance information to estimate T_a. Since the random trials would be used, at least initially, to evaluate learning in the increasing trials any learning effect may be confounded with the convergence that occurs in the random trials. Learning may also be hampered, although as it is intended to instruct the participants to cross after a specific van number this may not be the case (see Section 4.3.6.2 on training). The results from Experiment 2 should indicate whether the effect for the random trials is robust but separate experimentation will need to be conducted to investigate the increasing trials.

4 Experiment 2

4.1 Method

4.1.1 Participants

Thirteen males and 22 females between the ages of 18 and 24 (mean = 22, sd = 1.7) participated in this experiment. All but six were University of Canterbury students (five non-students and one Lincoln University student).

4.1.2 Materials and Apparatus

The actual and virtual environments were identical to those in Experiment 1, as were the host computer and helmet-mounted displays.

4.1.2.1 Hardware

A commercial leg brace was procured due to there being only a marginal decrease in walking speed between the two conditions for Experiment 1. It was a Lifecare Range-of-Motion knee brace, manufactured by South Island Orthodics, a Christchurch, New Zealand, based company. The leg was locked completely straight (0˚ flexion and extension). See Figure 9 for pictures of the brace, from the side and from the front, as it was worn in the experiment.

Figure 9. The leg brace from the side (left) and front (right).

4.1.3 Design

There were a maximum of 68 trials for this experiment. The initial 8 trials were identical to those in Experiment 1 and the instructions given to the participants were also identical. The 60 experimental trials in the virtual environment consisted of 10 blocks of trials, each having two sets of three unique trials (the 40-, 50-, and 60-m initial distances). The increasing trials used in Experiment 1 were not used so within each set all trials were randomised. For the first and final block of trials the participant was unimpaired. The leg brace was attached and worn for the intervening blocks. Each participant was tested for as many blocks as possible, up to a maximum of 10 blocks, in the time available (approximately 30-40 minutes to allow time for slower walkers and completion of the RTQ). If a participant was unable to complete 10 blocks in the time available their final block was always unimpaired. Their final two blocks were always coded 9 and 10 even if they did not complete this many.

The two sets were used to reduce the likelihood that two trials of the same type would occur sequentially. The data for the two sets was pooled before analysis. Table 4 is a summary of the independent variables and Table 5 is a summary of the dependent variables for Experiment 2.

Table 4. Independent variables for Experiment 2.

Variable	**Description**	**Number of levels**	**Levels**	**Unit**
Block	Two or eight clusters of trials within conditions. Blocks 1 and 2 are unimpaired while the are impaired.	2 or 8	1^{st} to 10^{th}	-
Initial Distance Between Vans	The distance between the rear of a vehicle as it passes the participant and the front of the next vehicle	3	40, 50, 60	m

Table 5. The dependent variables for Experiment 2.

Variable	**Description**	**Unit**
Safety Ratio	The ratio of the available crossing time from when the participant moves 0.5 m from the starting point by the time taken to cross to the far edge of the van	-
Unsafe Crossings	Crossings in which the participant was either hit or within 0.5 s of being hit	-
Walking Speed	The speed with which the participant crossed from 0.5 m to the far edge of the lane	m/s
Percentage of Available Gap Used	The percentage of the available gap used by the participant	-
Gap Number Chosen	The ordinal number of the gap that the participant chooses; 1^{st}, 2^{nd}, etc.	-

The dependent variables are the same as those used in Experiment 1 with two minor changes:

- The T_a of the van when the participant begins moving, used by both the safety ratio and gap proportion variables, is now taken from when the participant moves further than 0.5 m from the starting point.

- The crossing end point of the safety ratio is now taken as the far edge of the van rather than the centre of the road.

The position from which T_a was measured was changed to ensure that the value related to an actual crossing attempt rather than body sway or possibly an aborted crossing attempt. The crossing end point for the safety ratio was changed to reflect when the participant was no longer in danger of being hit.

4.1.4 Procedure

Each participant was given time to read the description and instruction sheets (Appendices C and D) and sign a consent form (Appendix E). They were then asked to fill in the SSQ. Participants were informed that they could withdraw from the experiment at any stage. The participants were positioned on a red strip of tape on the floor slightly to the right of the transmitter. They were able to use this strip as a way of repositioning themselves at the beginning of each new trial (they were instructed to raise the helmet slightly to see the floor once they had returned to the starting point). They were instructed to walk towards the street light and, on the return, to walk towards the tree (see Figure 1). Equipment and furniture in the room were positioned so as to minimise the risk of collision. At the end of each trial a black screen with white text instructed the participant to prepare for the next trial, and there was also a verbal message with the same purpose. After 6 trials (1 block) the leg brace was attached. They were asked which foot they would kick a ball with and then the brace was attached to the other leg. Once they had completed 48 trials with the leg brace attached or time was becoming short, the leg brace was removed and they completed the final 6 trials without the brace. At the end of the experiment participants completed a post-test SSQ and also the RTQ.

4.2 Results

Of the 35 participants tested 13 had at least one maximally cautious crossing, i.e. crossing after all of the vans had passed. How many cautious crossings occurred and when they occurred will be discussed in Section 4.2.8. Data for a cautious crossing could not be analysed as four of the dependent variable require information about the gap crossed in and the fifth, walking speed, is useless if they are just crossing the road without any vans. The final segment of a trial like this bears more resemblance to a familiarization trial rather than an experimental trial since they are just crossing an empty road. The data points for these cautious crossings were replaced by the nearest similar data point for that participant. For example, missing data in a 60-m initial distance impaired trial would be replaced by data from a trial in the same condition, generally an earlier trial. An earlier trial was not used if this would involve using a trial from a different condition. This technique reduces some of the variability within a participant's data, but since the replacement data has come from their individual performance variability between participants is maintained.

Two participants were removed from analysis. One participant only crossed cautiously, so her data could not be analysed. Another crossed cautiously on 18 of 48 trials. This was deemed to be too great a number of cautious crossings, as 37.5% of their data would be replicated, and their completion of only 48 trials means that they would be included in three of the analyses but excluded from the fifth (see below). The next highest number of cautious crossings was 13 out of 60 trials, which is approximately 21%. As they completed all of the remaining 60 trials they were retained. No other cautious participant had more than 8 cautious crossings and most had fewer than 5.

Each dependent variable was analysed with three 2-way (2 blocks x 3 initial distances) ANOVAs with repeated measures on all factors and one 2-way (8 blocks x 3 initial distances) ANOVA with repeated measures on all factors. The first three ANOVAs compare the unimpaired and impaired conditions, i.e. when the leg brace was attached and when it was removed (Blocks 1 and 2, and Blocks 9 and 10), and compare Blocks 1 and 10 within the unimpaired condition. The final ANOVA is to investigate changes over blocks in the impaired condition (Block 2 through 9). The analysis for the comparison between the walking speed conditions (the means for the actual and virtual environments in the familiarisation trials and the maximum experimental walking speed) will be described Section 4.2.3.1. Effect sizes and power analyses for the main effects are presented in Appendix G.

4.2.1 Safety Ratio

4.2.1.1 Block Effects

Comparison of Block 1 to Block 2. There was a non-significant decrease of 13% for the safety ratio when the brace was attached, from 1.71 to 1.58 for the unimpaired and impaired trials respectively, $F(1,32) = 4.05$, $p = .053$. There was a significant main effect of initial distance between vans, $F(2,64) = 3.43$, $p < .05$, with safety ratios being lowest at the 50-m initial distance (1.56) and higher for the 40-m than 60-m initial distance (1.75 and 1.63 respectively). Figure 10 presents these two main effects and the non-significant interaction. Although people are safer when initial distance is shorter (40 m compared to 50 and 60 m), which replicates previous findings (Owen et al, 2002), the 50-m distance is associated with the lowest safety ratio, not the 60-m distance. This will be discussed further in Section 4.3.1.

Comparison of Block 9 to Block 10. Mean safety ratio significantly increased by 15% when the leg brace was removed, from 1.81 to 1.96 for the impaired and unimpaired trials respectively $F(1,32) = 7.56$, $p < .05$. The main difference seems to be occurring at the 60-m

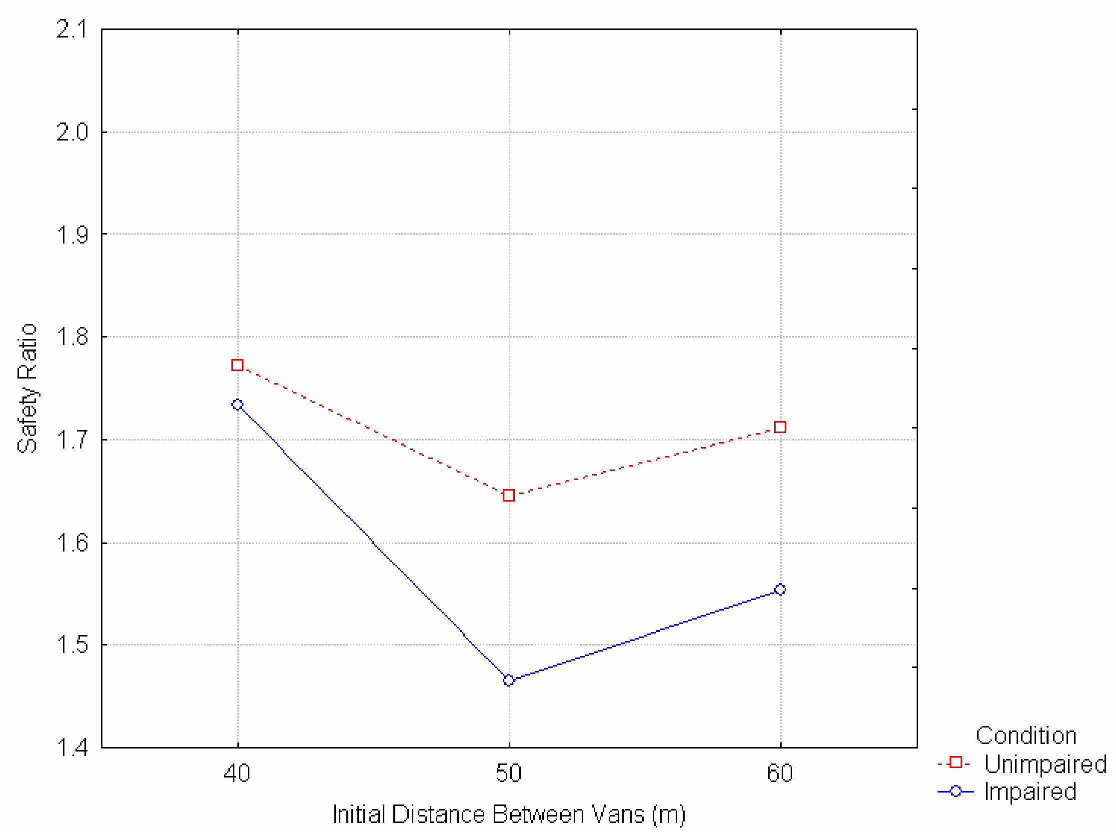

Figure 10. Safety ratio as a function of initial distance between vans and the mobility conditions for Block 1 (unimpaired) and Block 2 (impaired).

initial distance (see Figure 11). There is no significant Distance main effect nor an interaction with mobility, but there is a large difference between the unimpaired and impaired safety ratios at 60 m (0.31, compared to an average of 0.07 at 40 and 50 m). While the impaired block follows the expected trend with safety ratios decreasing as distance increases, the unimpaired block shows the same trend as Blocks 1 and 2, with the 50-m initial distance having the lowest safety ratio.

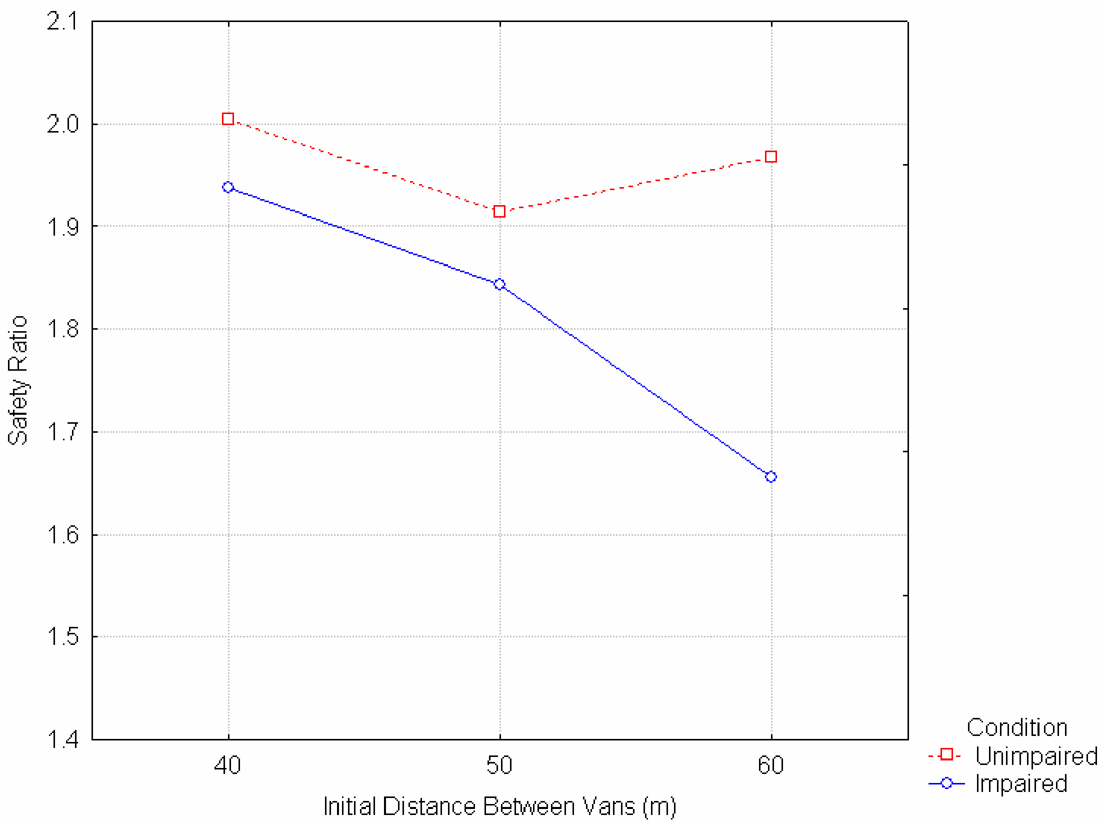

Figure 11. Safety ratio as a function of the mobility condition and initial distance between vehicles for Block 9 (impaired) and Block 10 (unimpaired).

Comparison of Block 1 to Block 10. The mean safety ratio increased by 25% from the first unimpaired block (1.71) to the last (1.96), $F(1,32) = 10.31$, $p < .05$. This improvement cannot be attributed to an increase in unimpaired walking speed as there was no significant increase. It seems likely that this is due to attunement to the impaired walking speed. From Block 1 to Block 2 there was a 13% decrease in safety ratio while from Block 9 to Block 10 there was a 15% increase, a change of similar magnitude. Although there was no significant main effect of distance, both blocks displayed the same trend with the 50-m initial distance having the lowest safety ratio (compare the unimpaired trends on Figures 9 and 10).

Comparison of Blocks 2 through 9. There were significant main effects of block, $F(7,224) = 4.19$, $p < .05$, and initial distance between vehicles, $F(2,64) = 25.91$, $p < .05$. Figure 12 presents the main effect of block as well as the linear regression fit for Blocks 1 and 10 (unimpaired) and Blocks 2 though 9 (impaired). As initial distance increased, safety ratio decreased as expected (1.86, 1.73, 1.60 for 40, 50, and 60 m respectively). Only Block 2 had the lowest safety ratios at the 50-m initial distance. As mentioned in the previous comparison, the changes in the safety ratio when the mobility condition changes appear to be of a similar magnitude. As Figure 12 indicates, the linear regression fits are also similar for the unimpaired and impaired blocks, the difference between the two regression lines consistently being 0.11, or 11%. This is further evidence that the initial decrease in the safety ratio when the brace was attached was partially due to the participants being attuned to their unimpaired walking speed, and that the increase when the brace was removed was due to being attuned to their impaired walking speed. Overall there was approximately a 2.8% increase in the safety ratio over blocks, consistent for both the unimpaired and impaired trials.

4.2.2 Unsafe Crossings

The results for unsafe crossings should be similar to those for the safety ratio, at least in general

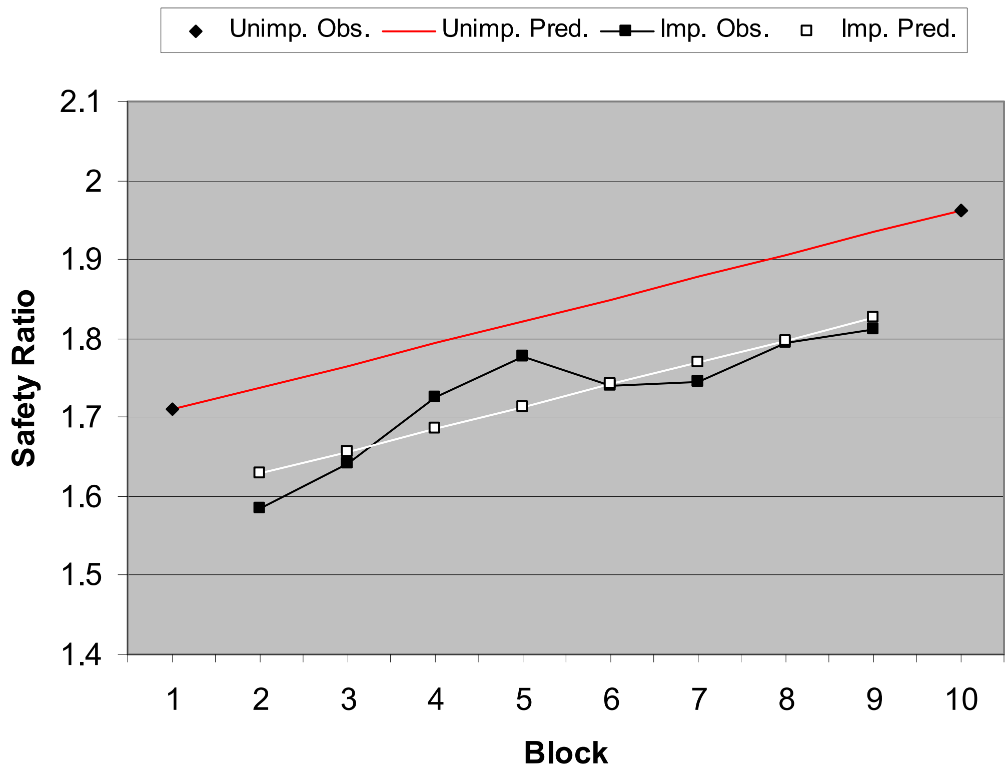

Figure 12. Safety ratio for Blocks 2 through 9 (impaired), and the linear regression fit for Blocks 2 though 9 (impaired) and Blocks 1 and 10 (unimpaired). Obs. indicates the observed values and Pred. indicates the linear regression fit.

trend. A decrease in safety ratio does not mean that an unsafe crossing has occurred but should be related to an increase in unsafe crossings. The safety ratio has a far greater range than unsafe crossings; a safety ratio of 2 will not be unsafe, and assuming the T_a of the van is greater than 1-s nor will a ratio of 1.5. This means that a change in safety ratio from 2 to 1.5 will result in no change in unsafe crossings.

4.2.2.1 Block Effects

Comparison of Block 1 to Block 2. The slight decrease in unsafe crossings when the brace was attached (from 39% to 38%, p = .86) demonstrates the previous point. While the decrease in safety ratio neared significance, there was no equivalent increase in unsafe crossings, rather there was a negligible decrease. The effect of initial distance, $F(1,32) = 11.48$, $p < .05$, presented the same pattern as the equivalent effect on the safety ratio, with more unsafe crossings (45%) at the 50-m initial distance than at the 40- or 60-m initial distances (33% and 39% respectively).

Comparison of Block 9 to Block 10. No main or interaction effects were significant for these blocks. There was a decrease in unsafe crossings when the leg brace was removed, from 28% to 21%, $p = .14$. Unsafe crossings increased as initial distance between vans increased (20%, 26%, and 28% for 40, 50, and 60 m respectively), $p = .34$. The same general pattern was exhibited in the safety ratio. Both the impaired and unimpaired blocks were similar at the 40- and 50-m initial distances. At the 60-m initial distance there was an increase in unsafe crossings for the impaired trials but a decrease, almost to the 40-m level, in the unimpaired trials.

Comparison of Block 1 to Block 10. Unsafe crossings dropped significantly across the unimpaired blocks, $F(1,32) = 11.78$, $p < .05$, from 39% to 21%. This is very similar to the comparable effect for the safety ratio, and as with the safety ratio this may be related to attunement to the impaired walking speed. Initial distance showed the same trend, although non-significant, as for the safety ratio, a greater percentage of unsafe crossings occurring at the 50-m initial distance (27%, 34%, and 30% for 40, 50, and 60 m respectively).

Comparison of Blocks 2 through 9. Although the main effect of block (see Figure 13) was not significant, $p = .21$, a general downward trend mirrored the effect on the safety ratio, an overall a 10% decrease from the first to the last impaired block. An increase in initial distance was related to an increase in unsafe crossings (24%, 33%, and 41% for 40, 50, and 60 m

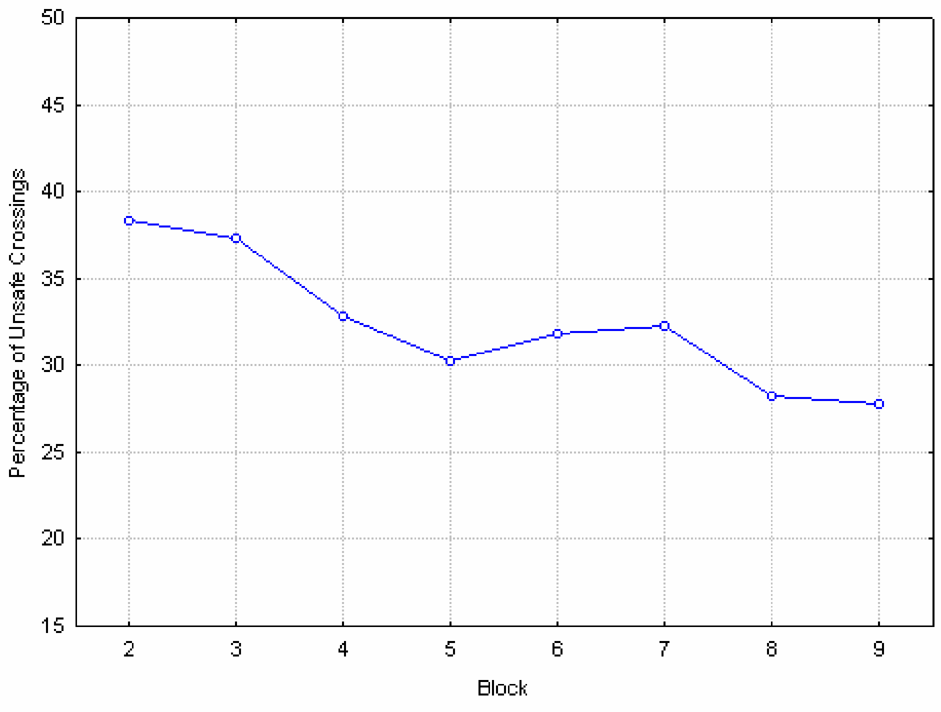

Figure 13. Unsafe crossings for Blocks 2 through 9 (impaired).

respectively), $F(2,64) = 15.43$, $p < .05$. This is also similar to the effect on the safety ratio (see Figure 12,), although inversed.

4.2.3 Walking Speed

4.2.3.1 Comparisons Between Actual Environment, Virtual Environment, and Maximum Virtual Walking Speeds

The values for the walking speeds in the actual normal and rushing trials are based on the first two trials. For the virtual normal and rushing trials these are based on averages of three familiarization trials. The maximum virtual walking speed is the fastest walking speed recorded during the experimental trials.

The 1-way (5 conditions) repeated measures ANOVA revealed a significant effect of condition, $F(4,128) = 125.79$, $p < .05$ (see Figure 14). Tukey's honest significant difference post hoc test revealed significant differences between all of the conditions, $p < .05$, except the normal walking speed in the actual and virtual conditions, although this was marginal ($p = .076$). For the actual environment there was a 57% increase in walking speed between the normal and rush conditions, while there was a 60% increase for the same conditions in the virtual environment. There was a 15% decrease in walking speed between the actual and virtual environments in the normal speed condition and a 14% decrease in the rushing condition. This indicates that the effect of asking the participants to rush was equivalent between the two environments, but that participants walked slower initially in the virtual environment. The maximum walking speed obtained in the experimental trials was 30% higher than with the rushing instruction in the actual environment and was 51% higher than with the rushing instruction in the virtual environment. As a reminder, the shortest time-to-cross in the virtual trials was used to individuate the gaps.

4.2.3.2 Block Effects

Comparison of Block 1 to Block 2. Once the leg brace was attached there was a significant decease in walking speed, $F(1,32) = 25.32$, $p < .05$, from 1.72 to 1.52 m/s on average for unimpaired and impaired respectively. There were no other main or interaction effects.

Comparison of Block 9 to Block 10. Once the leg brace was removed walking speed increased significantly, $F(1,32) = 15.58$, $p < .05$, from 1.63 to 1.74 m/s for impaired and unimpaired

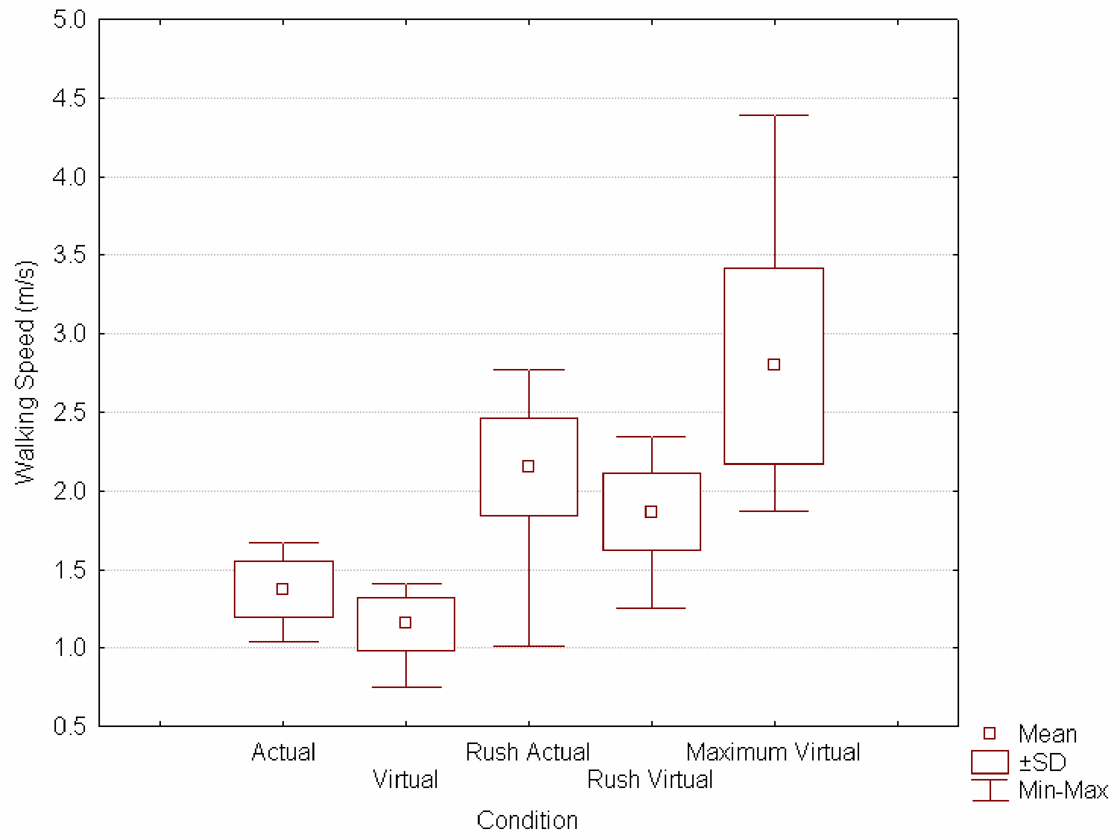

Figure 14. The mean, standard deviation, and range of the walking speeds across the different conditions. Actual refers to the participant's normal walking speed in the actual environment with the HMD balanced on their head. Virtual refers to the mean walking speed of the first three virtual environment familiarization trials during which the participants were asked to walk normally. Rush Actual refers to the participant's walking speed in the actual environment when asked to walk as if in a rush. Rush Virtual refers to the mean walking speed of the last three virtual reality familiarization trials during which the participants were asked to walk as if in a rush. Maximum Virtual is the fastest walking speed obtained by each participant in the experimental trials.

respectively. This is further evidence that it was the leg brace, and no other outside factors, that affected the mobility of the participant.

Comparison of Block 1 to Block 10. There was no significant change in walking speed between the first (1.72 m/s) and last (1.74 m/s) unimpaired blocks, p = .55, an increase of only 0.02 m/s.

Comparison of Blocks 2 though 9. There was a significant main effect of block, $F(7,224) = 3.21$, $p < .05$ (see Figure 15), due mostly to a steady increase until Block 5 at which point it generally flattens except for the dip at Block 8. There was also a main effect of initial distance, $F(2,64) = 4.93$, $p < .05$, with participants walking slower as initial distance increased (1.62, 1.59 and 1.58 m/s for 40-, 50-, and 60-m initial distances respectively).

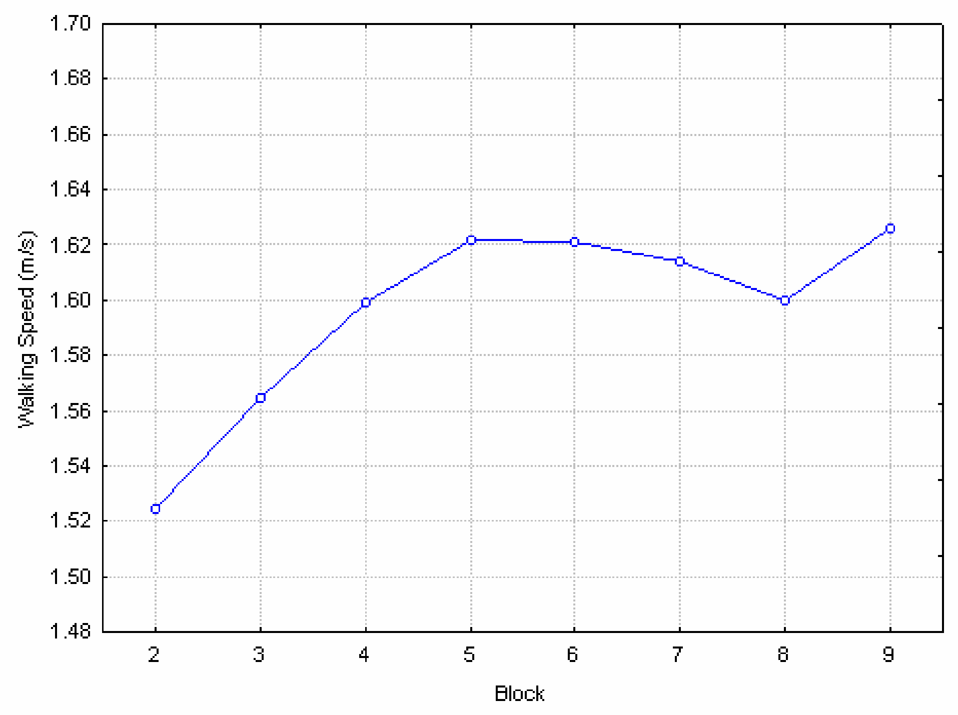

Figure 15. Walking speed for Blocks 2 through 9 (impaired).

4.2.4 Percentage of Available Gap Used

4.2.4.1 Block Effects

Comparison of Block 1 to Block 2. There was a main effect of initial distance between vehicles,

$F(2,64) = 8.97$, $p < .05$. As initial distance increased the percent of the gap used decreased (73%, 68%, and 67% for 40, 50, and 60 m respectively). Although there was a significant effect of mobility condition for walking speed there was no comparable effect for percentage of the gap used, $p = .86$. Figure 16 (top panel) shows the main effect of initial distance with the non-significant interaction with mobility condition. However, there was a slight change in trend for the impaired trials, the same percentage of the gap being used for both the 50- and 60-m initial distances for the impaired trials but with the 60-m distance related to the smallest percentage of the gap used for the unimpaired trials (see Figure 16, top panel).

Comparison of Block 9 to Block 10. As with the previous analysis, when the initial distance increased the percentage of the available gap used decreased (78%, 75%, and 73% for 40, 50, and 60 m respectively), $F(2,64) = 10.45$, $p < .05$. The percentage of the gap used did not change significantly when the brace was removed, $p = .43$. Figure 16 (bottom panel) shows the main effect of initial distance along with the non-significant interaction with mobility condition.

Comparison of Block 1 to Block 10. There was a main effect of block, $F(1,32) = 22.07$, $p < .05$, with participants using less of the available gap in Block 1 (69%) than in Block 10 (76%). The main effect of initial distance between vans was also evident, $F(2,64) = 10.22$, $p < .05$. As initial distance increased participants used less of the available gap (75%, 72%, and 70% for 40, 50, and 60 m respectively). The lack of an interaction, $p = .82$, indicates that although they are using more of the gap at the end of the experiment than at the start, they are still attending to distance information when deciding how long to wait before crossing. This has implications for training as it means that there is very little degradation in the effect of distance over blocks, even though

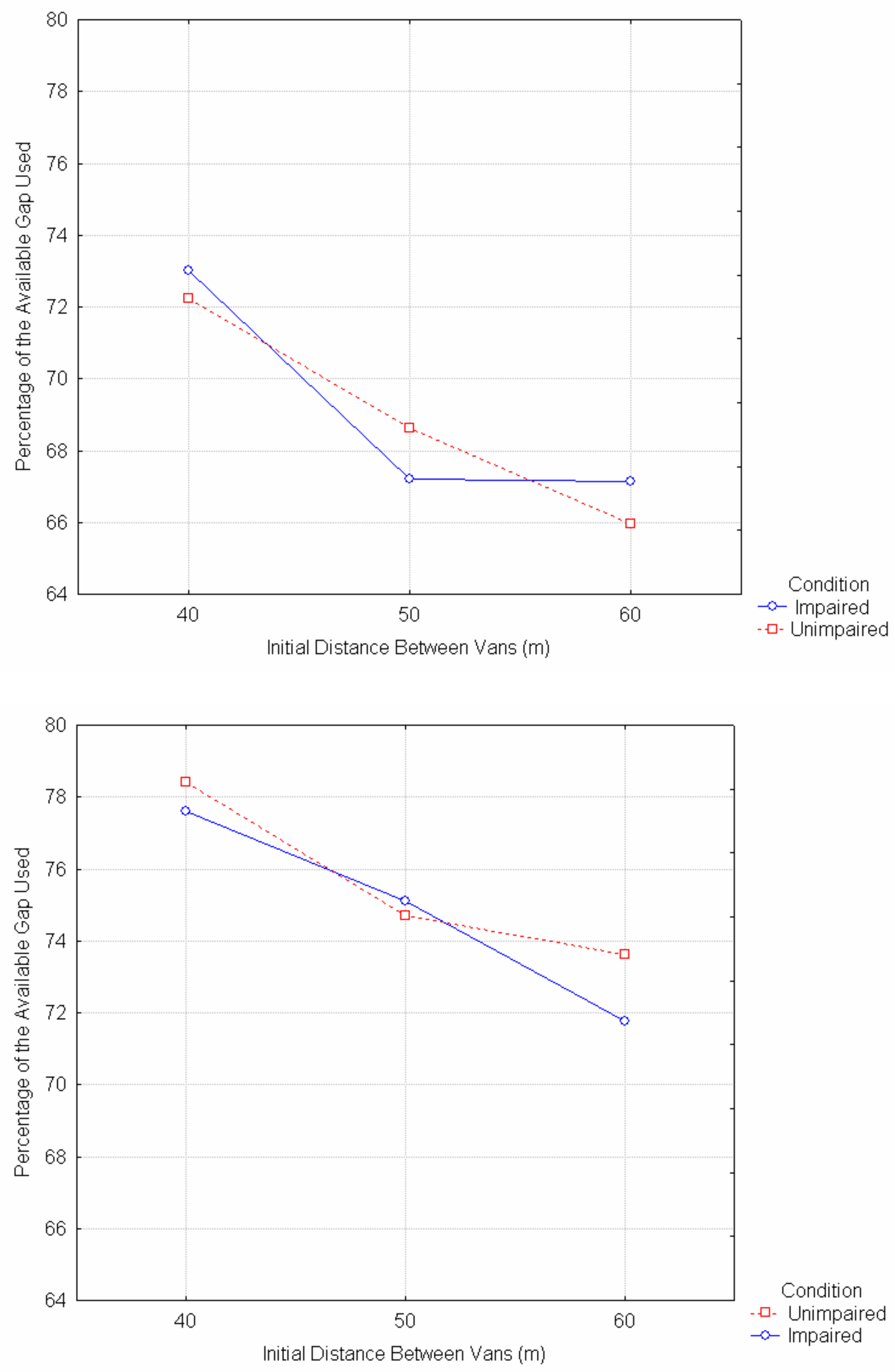

Figure 16. The main effect of initial distance between vans as a function for the brace being attached (Block 1 to Block 2; top panel) and removed (Block 9 to Block 10; bottom panel)

overall the participants are using more of the available gap. If training is successful it is expected there will be an increase in the percentage of the gap used as well as the reduction, if not the complete absence, of differences between the three initial distances.

Comparison of Blocks 2 through 9. Over time the participants used a greater percentage of the gap, $F(7,224) = 7.71$, $p < .05$ (see Figure 17). There was also a main effect of initial distance between vans, $F(2,64) = 41.52$, $p < .05$. The same trend as previously noted for the preceding analyses is repeated here, with participants using more of the gap when the initial distance is smaller (76%, 72%, and 69% for 40, 50, and 60 m respectively). Overall, the two variables affecting how long the participants waited to cross are the initial distance between vehicles and length of time in the simulation, the latter suggesting a learning effect. Whether they were mobility impaired or not had no effect.

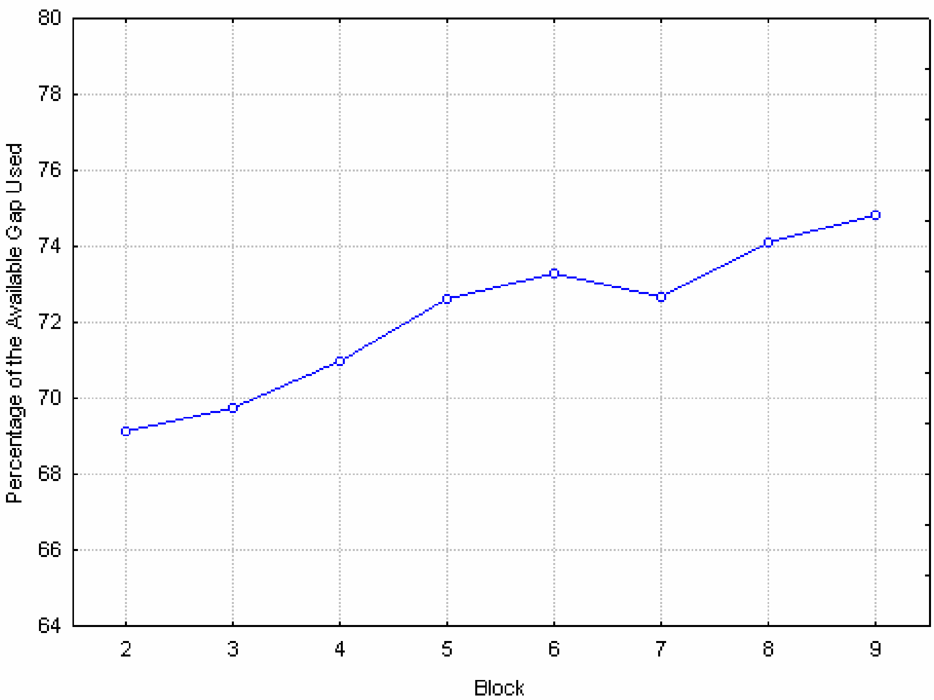

Figure 17. Percentage of the available gap used for Blocks 2 through 9 (impaired).

4.2.5 Gap Number Chosen

The gap number does not reflect safety. Since the different sized gaps within a trial are randomized, the first gap may be the shortest or the longest. Gap number chosen may relate to impulsivity in that people who are more impulsive may tend to cross sooner, whereas those who are more cautious may cross later. This will be discussed in Section 4.2.8.

4.2.5.1 Block Effects

Comparison of Block 1 to Block 2. As the initial distance between vans increased, participants crossed sooner (average gap 4.20, 3.02, and 2.53 for 40, 50, and 60 m respectively), $F(2,64) = 23.70$, $p < .05$. Participants crossed slightly later at the 40-m initial distance in the impaired mobility condition (about half a gap later on average) but were about the same as the unimpaired condition for the other two initial distances (see Figure 18).

Comparison of Block 9 to Block 10. Participants crossed earlier in the line of vans after the leg brace was removed (3.05 and 2.49 for impaired and unimpaired respectively) , $F(1,32) = 11.42$, $p < .05$. The same Initial Distance main effect was repeated, $F(2,64) = 19.74$, $p < .05$, with participants crossing sooner when initial distance was greater (see Figure 19). The lack of a Mobility Condition effect when the brace was initially attached, whereas there was an effect when it was removed, may relate to participants not realising that their walking speed has not increased from the first block. If this is the case they may have been willing to cross sooner as they felt that their walking speed had increased significantly, which it had but not to the same extent as it had decreased initially.

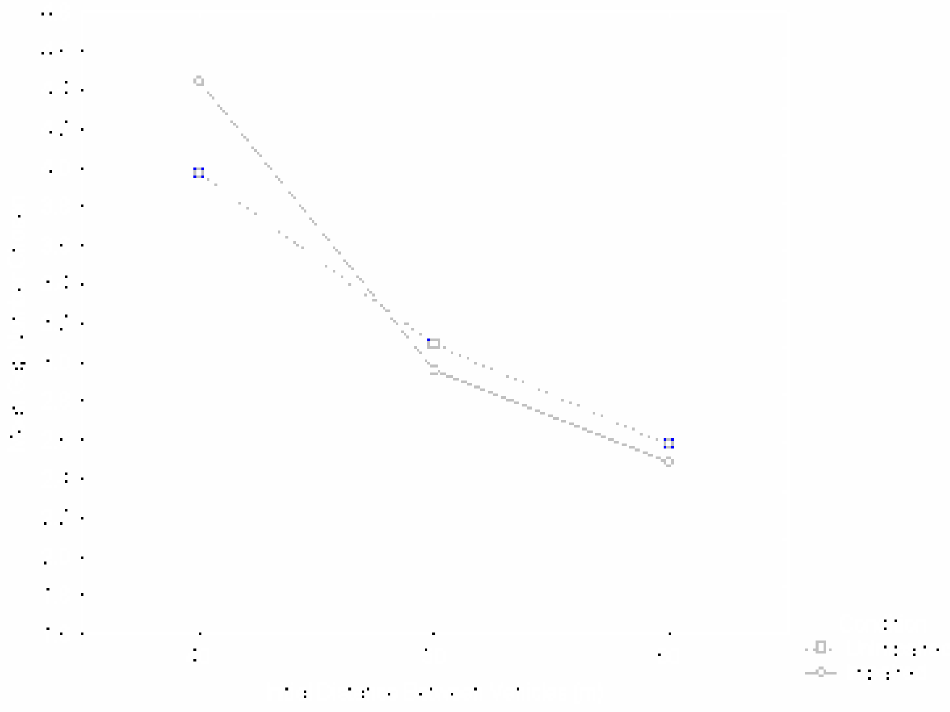

Figure 18. Mean gap number chosen as a function of initial distance between vans. There is no significant effect of mobility condition.

Figure 19. Mean gap number chosen as a function of initial distance between vehicles and the mobility conditions for Block 9 (impaired) and Block 10 (impaired).

Comparison of Block 1 to Block 10. There was a significant main effect of block for the mean gap chosen, $F(1,32) = 6.38$, $p < .05$, with participants crossing later in Block 1 than Block 10 (3.21 and 2.49 respectively). Initial distance between vans was also significant, $F(2,64) = 17.27$, $p < .05$, participants again crossing sooner when initial distance was longer (3.52, 2.77, and 2.27 for 40, 50, and 60 m respectively). The effect of block cannot be attributed to an increase in walking speed as there was no significant difference between the two blocks.

Comparison of Blocks 2 through 9. There was a main effect of initial distance between vans, $F(2,64) = 50.73$, $p < .05$, the same trend occurring as noted in the previous three analyses (3.85, 2.90, and 2.56 for 40, 50, and 60 m respectively). Although there was no main effect of block there was an interaction between block and initial distance, $F(14, 448) = 1.8$, $p < .05$ (see Figure 20). There was a general convergence between the three levels of initial distance possibly indicating that participants were beginning to attend more to T_a information. Figure 24 contains the linear regression fit for each level of initial distance. This is the same trend that occurred with the random trials for gap number chosen in Experiment 1 (see Figure 7).

4.2.6 Relationships Among the Dependent Variables

To ascertain the relationships between the dependent variables, correlations were calculated between the variables for the overall mean, the mean across all ten blocks, and for the mean of each block. Significance was based on the .0045 level to reduce the risk of familywise error: .0045 is .05 / 11 (since 11 correlations were calculated). This provided a cutoff *r* of approximately .49 (N=33). Appendix G contains the full correlation matrices.

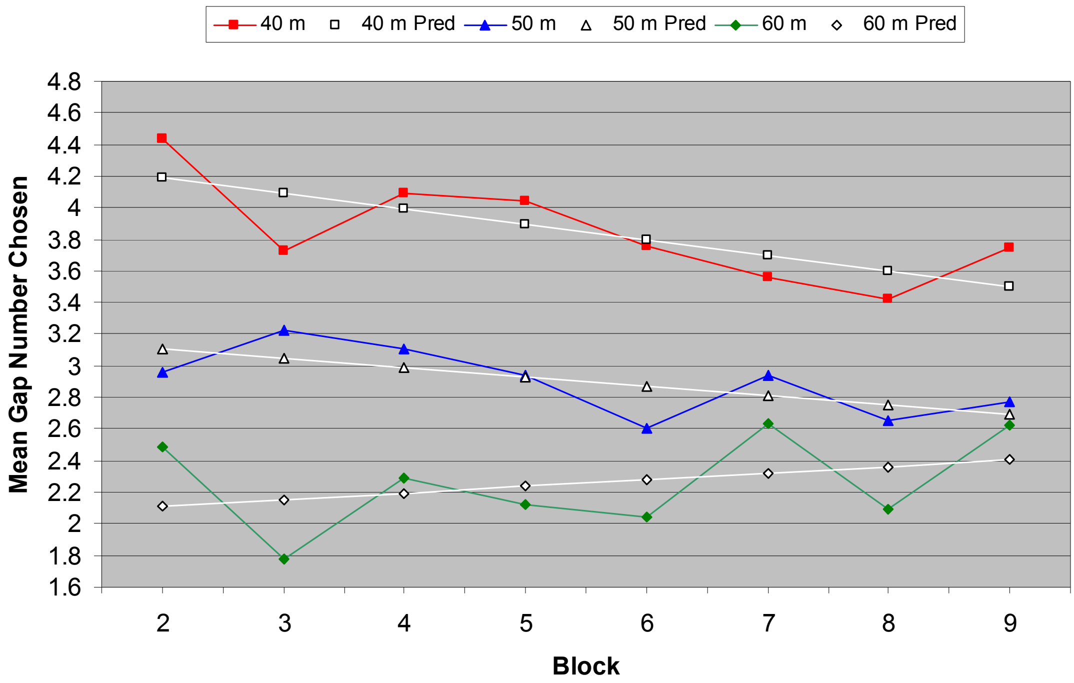

Figure 20. Gap number chosen as a function of initial distance between vans for Block 2 through 9. *Pred.* indicates the linear regression fit for each level of initial distance over blocks.

In general the overall mean for safety ratio correlated highly with the overall means of the other variables (r = .58, -.78, and .55 for walking speed, unsafe crossings, and percentage of the available gap used respectively), except gap number chosen. A negative correlation with unsafe crossings is not unexpected as the previous results show that unsafe crossings tend to exhibit the inverse of the trend shown by the safety ratio (see Figures 18 and 19). Overall there was only one significant correlation between safety ratio and gap number chosen and this was for the tenth block, r = -.49. This may be related to the participants tending to cross sooner for this block of trials than any other block as the highest safety ratios were also recorded for this block. Crossing earlier did not make the participants safer, however. In all likelihood there is no direct relationship between these variables.

Aside from the safety ratio there were very few relationships between the other variables. The only consistent correlations were between unsafe crossings and percentage of available gap used, perhaps related to the relationship between percentage of the gap used and the safety ratio. An influence on the safety ratio is likely to be reflected in unsafe crossings. It is interesting to note that there are no significant correlations between walking speed and the proportion of the available gap used. The previous results (see Sections 4.2.1, 4.2.3, and 4.2.4) suggest that these two variables affect the safety ratio independently, and the results of the correlations support this.

4.2.7 Cautious Crossings

Although cautious crossings, crossings where the participants waited until all the vans passed before crossing, cannot be analysed statistically using the repeated measures design, it is of interest to see if there is any trend as to when they occurred. For the purposes of this analysis the participant who was excluded due to too many cautious crossings compared to the number of completed trials will be included. The participant who was excluded due to only making cautious crossings will not be included as, unlike the other participant, their cautious crossings are not informative.

Of the 12 included cautious crossers, 9 were female and 3 male. This approximates to 45% of the females and 23% of the males. The sexes were equally distributed, $\chi^2(1,34) = 1.38$, $p = .24$, although if this trend continued with a larger sample size it seems likely the test may reach significance. There were 65 cautious crossings overall, or 3.2% of the total crossings.

There were definite trends evidenced in the cautious crossing data. More cautious crossings occurred at the 40-m initial distance between vans than at the other two levels combined (34, 22, and 9 for 40, 50, and 60 m respectively). There was also a decrease in cautious crossings over blocks. The relatively high levels of cautious crossings over the first three blocks soon decreased to almost none (see Figure 21 for the number of cautious crossings at each block for each level of initial distance). There was no real difference between impairment conditions, each having about the same mean number of cautious crossings per block (7 and 6.13 for unimpaired and impaired respectively). As Figure 21 shows, the numbers of cautious crossings were fairly similar across the three levels of initial distance between vans for Block 1. For the first two impaired blocks there is an increase in the number of cautious crossings at the 40-m initial distance and a decrease at the 60-m initial distance. The total number of cautious crossings did not change to any large extent for these blocks (12, 13, and 14 for Blocks 1, 2, and 3 respectively).

4.2.8 Individual Differences

4.2.8.1 Differences in the Effect of Mobility Impairment on the Safety Ratio

Although in general there was a decrease in safety when the brace was attached and an increase when it was removed, supporting one prediction regarding safety, it was also predicted that participants may be as safe, if not safer, with the leg brace attached, an alternate prediction. The differences in each individual's safety ratios between Blocks 1 and 2, and Blocks 9 and 10, was calculated. They were categorised into four groups: consistently safer without the brace (*safer without brace*); consistently safer with the brace (*safer with brace*); safer without the brace

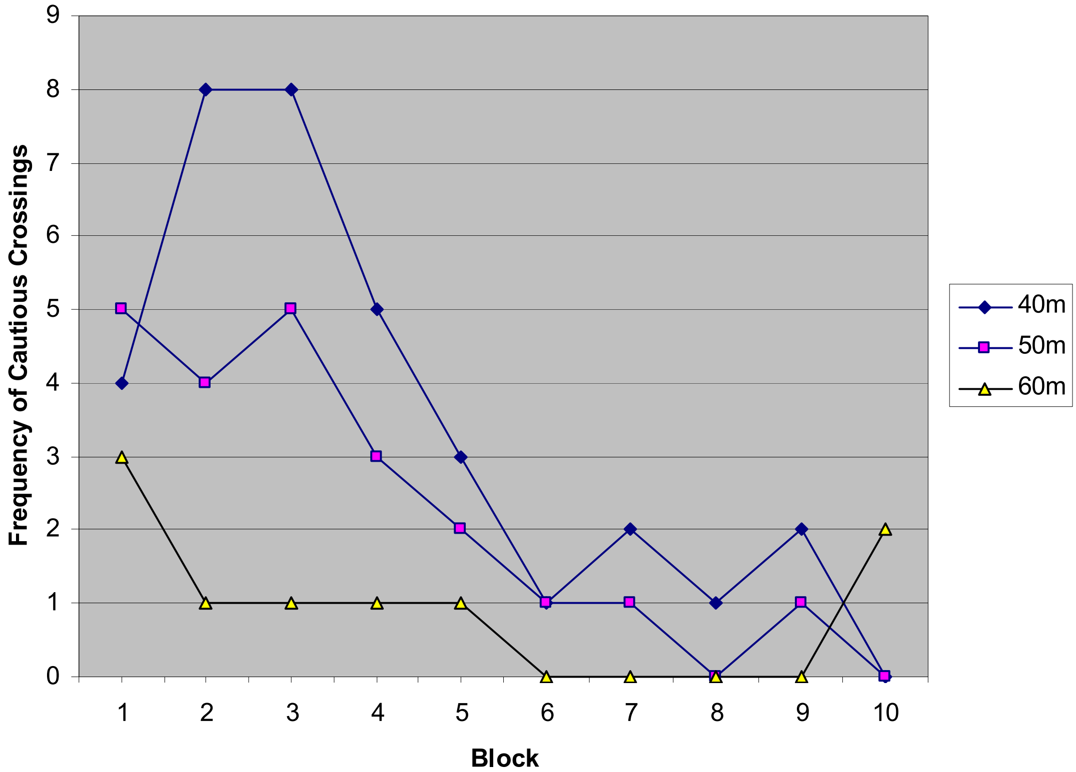

Figure 21. The frequency of cautious crossings over blocks and levels of initial distance between vans.

between Blocks 1 and 2 but not Blocks 9 and 10 (*initially safer without brace*); and safer with the brace between Blocks 1 and 2 but not Blocks 9 and 10 (*initially safer with brace*). There were no differences in the percentages of cautious and non-cautious crossers in each category

Table 6. Individual differences in the change in safety ratio between mobility conditions.

Safer Without Brace	**Safer With Brace**	**Initially Safer Without Brace**	**Initially Safer With Brace**
11 (33%)	3 (9%)	7 (21%)	12 (36%)

Overall, when the brace was attached 18 participants became less safe (mean decrease 38%) and 15 became more safe (mean increase 18%). When the brace was removed 23 participants became more safe (mean increase 29%) while 10 became less safe (mean decrease 18%). This indicates that while many of the participants were safer without the brace, not all were, and some varied between being safer without the brace and safer with the brace. The hypothesis that participants would be safer without the brace was supported overall, but it is possible that the finding may only generalise to one segment of the population. While the majority of the participants were safer without the brace for each mobility condition comparison (i.e. Block 1 to Block 2 and Block 9 to Block 10), 66% of the participants were safer with the brace for at least one of the two comparisons. With the relatively small sample size it is difficult to determine how robust these effects are.

4.2.8.2 Risk-Taking

To examine risk-taking correlations have been calculated. Two of the three scales, *would do* and *risk assessment*, of the RTQ are discrete and the third, *have done*, is dichotomous. As four of the five dependent variables are continuous, the exception being unsafe crossings, correlations were preferred to dividing the two continuous RTQ scales into groups arbitrarily. For correlations between two continuous variables Pearson's r has been used. For dichotomous variables the *point-biserial* coefficient (r_{pb}) has been used.

There was only one significant correlation between the three scales of the RTQ (would do correlated with risk assessment, $r = -.44$, $p<.05$) A willingness to take part in more of the activities was associated with lower risk assessment scores. This suggests that the participants who viewed many of the activities as quite risky were not willing to do as many such activities. The other correlations were in the expected direction but were not significant. The correlation between would do and with have done was $r_{pb} = .34$. The correlation between have done with risk assessment was $r_{pb} = -.25$, consistent with Horvath and Zuckerman's (1993) finding.

For comparison with the three scales the overall mean for each dependent variable was calculated for each participant, as were the means for each block (1 through 10) for the dependent variables. There were only small, if any, relationships between the three scales and the dependent variables. The largest correlations overall came from the relationships between the scales and gap number chosen. Three were significant: $r = .41$ for risk assessment (for the second block), and $r = -.35$ and $-.39$ for would do (for Blocks 3 and 10 respectively), $N = 33$, $p < .05$. The large number of correlations make it possible that these are chance occurrences. The correlations with gap number chosen show the strongest relationships, negative correlations with what the participants are willing to do and positive correlations with risk assessment. Since low numbers for gap number chosen reflect participants who cross sooner these trends make sense. A willingness to do more of the activities and a tendency to rate them as lower risk relate, although not significantly, to crossing sooner. Although in this situation, with the gaps randomly ordered within a trial, crossing sooner does not necessarily mean greater risk but may index impatience. An experiment including increasing trials, as used in Experiment 1, may help determine if this trend continues. In this instance how many of the activities the participants had done seems to have no effect.

4.2.8.3 Risk-Taking and Cautious Crossers

Risk taking can also be investigated by examining the two groups that emerged from the data; those that had no cautious crossings (22) and those that had at least one (13). Excluding the participant who crossed cautiously on every trial and the participant removed for having too many cautious crossings compared to overall crossings, this leaves 11 cautious and 22 non-cautious crossers respectively. Further correlations were calculated to investigate whether there were any relationships between the RTQ scales and cautious crossings. The groups, coded 0 for cautious and 1 for non-cautious, were also correlated with the dependent variables in the same way as described above for the RTQ scales.

Would do and group correlated significantly, r_{pb} = .36. The correlations for *have done* and *risk assessment* were r_{pb} = -.12 and r_{pb} = -.25 respectively, both non-significant. The non-cautious group have done slightly fewer of the activities than the cautious group (means of 16.36 and 17.63 respectively). The result for risk assessment is consistent with Horvath and Zuckerman's (1993) finding, though non-significant. There were almost no significant correlations between group and the dependent variables other than for gap number chosen. The only significant correlation with unsafe crossings was in Block 8, r_{pb} =-.49, $p < .05$, but the relevance of this is uncertain being that the other correlations for unsafe crossings vary in sign and magnitude. The correlations for gap number chosen are all significant bar for the first block, and they are all negative (see Table 7). This trend matches that found in the correlations between what the participants are willing to do and gap number chosen, which is not too surprising as there is collinearity between the former variable and group.

Table 7. Correlations between cautious/non-cautious and means for gap number chosen. *All* is the overall mean of all 10 blocks. Significant correlations are highlighted in grey.

		Block									
	All	1	2	3	4	5	6	7	8	9	10
Group	-0.61	-0.17	-0.45	-0.60	-0.47	-0.53	-0.60	-0.57	-0.41	-0.38	-0.47

4.2.8.4 *Differences Between the Cautious Crossers and Non-Cautious Crossers*

Examination of the mean differences between the groups supports the above analysis. Overall the non-cautious group had a slightly faster walking speed than the cautious group, only about .03 m/s faster. They walked a little slower in the first block, about .07 m/s, but were faster for all of the remaining blocks. They were also faster across all levels of initial distance, but these were again slight. The non-cautious safety ratios were higher on average, 1.80 compared to 1.65 for the cautious group, and were higher across all blocks and levels of initial distances. The differences for unsafe crossings mirror those of the safety ratio. The cautious group had approximately 5% more unsafe crossings than the non-cautious group (35% and 30% respectively). The non-cautious group tended to use about 2% more of the gap (73% compared to 71% for the cautious group). This was consistent across all blocks and levels of initial distance. Overall, the non-cautious group tended to be slightly safer across all variables than the cautious group. This suggests that the cautious group were aware they should be cautious.

The largest difference between the groups occurred for gap number chosen. Overall the non-cautious group chose to cross 1.5 gaps earlier than the cautious group (means of 2.56 and 4.02 respectively). In general, across all distances and blocks, the non-cautious group chose to cross at least one gap sooner than the cautious group.

4.2.9 Results Summary

Although overall the safety ratio was lower in the impaired condition, there was no equivalent increase in unsafe crossings due to impairment. Walking speed was significantly reduced by the leg brace, and when the brace was removed there was a significant increase. There was no difference across the unimpaired blocks for walking speed, unlike the same comparison for the safety ratio, but walking speed increased over the impaired blocks until reaching an approximate plateau around Block 5 (see Figure 14). Mobility impairment did not affect the percentage of the gap used, nor the mean gap number chosen. The initial distance between the vans had a significant effect on all of the variables except walking speed, indicating that, unlike previous forced-choice experiments (e.g. Owen et al, 2002), the decrease in safety ratio as distance increases is not related to participants walking slower when the vans are spatially further away. The analysis of risk-taking, using the RTQ and post-hoc comparisons between the cautious and non-cautious participants, suggests that higher levels of risk taking are associated with greater safety, although these differences were generally only marginal.

4.3 Discussion

4.3.1 Road-Crossing Safety

There was a decrease of 13% in the safety ratio, marginally significant, when the leg brace was attached. There was an even smaller change in the percentage of unsafe crossings (a 1% decrease overall) suggesting that the safety ratio may be a more sensitive measure of potential risk. Of course, it can be argued that it does not matter that the safety ratio has decreased if an unsafe crossing does not result. While this is true it is also important to be aware of a potential decrease in safety. The safety ratios in this experiment were quite high on average, above 1.4 (overall range 0.20 to 3.88, overall quartile range 0.81 to 2.62), which suggests that the safety ratio needs to be reduced substantially to produce an unsafe crossing. For comparison, the overall range from Owen et al (2002) was 0.70 to 2.09, while the overall quartile range was 0.88 to 1.48. Although the lower ends of the ranges are similar, the upper ends of the ranges are much higher in Experiment 2 than in Owen et al. A 0.5 decrease in the safety ratio was more likely to be linked to an unsafe crossing for Owen et al. than for Experiment 2. It should be noted that while the safety ratios from Experiment 2 and Owen et al are not directly comparable due to each being calculated slightly differently (compare Equations 2 and 6), the safety ratios in Experiment 2 are higher using the calculation from Owen et al (Equation 2). Also, any reduction in safety may be seen as increasing the potential risk to a person as it narrows their margin of safety. Taking 0.5 s longer to cross the road will not increase the risk of an accident if the van passes the persons position 1.5 s after they reach safety, but it means there is a smaller margin for error if they happen to stumble.

In this context, while the safety ratio is more useful than unsafe crossings for identifying general changes in safety, unsafe crossings are what will ideally be reduced by training (see Section 4.3.6.2). Improvements in the safety ratio should result in a decrease in unsafe crossings, although if the participant is very unsafe initially there may still be an undesirable number of unsafe crossings even if there is improvement in their safety ratio. If a participant is being hit frequently, an improvement may mean that they are hit less often but almost hit more often.

There was an unexpected occurrence in Blocks 1, 2, and 10. It was predicted that as the initial distance between vans increased the safety ratio would decrease. While this is true for the remaining seven blocks, for these three blocks the lowest safety ratio is associated with the 50-m initial distance. An initial interpretation, relating specifically to Block 2, was that more of the participants had received the 50-m initial distance as their first impaired block. Although this was the case, there was only a small difference in the proportion, .41 compared to .24 and .35 for the 40- and 60-m initial distances respectively. This may have been a great enough proportion if the safety ratios of those who received the 50-m level first were much lower than the others. There was a reasonable difference, about 35%, between the groups but the 50-m initial distance was still related to the lowest safety ratio. This same basic trend was exhibited in the percentage of the gap used, with the participants receiving the 50-m initial distance first using about 7% less of the gap but the other participants using less of the gap for the same initial distance. For unsafe crossings the participants receiving the 50-m initial distance first had more unsafe crossings, 86% compared to 63% for the others, and the same trend reoccurred. Although receiving the 50-m initial distance as the first impaired trial seemed to heighten the effect it does not explain it. On further examination this discrepancy only occurred in the first set of a block. The three blocks all relate to a change in condition, either the experimental trials commencing or the leg brace being attached or removed. Why this occurred is uncertain, and it may not be a robust effect. If this effect does not occur in future experiments it is probably random variation.

Across the impaired trials the participant's safety ratios increased by 23% over the first impaired block and about 10% over the initial unimpaired block. It appears that, unlike the finding by Warren & Whang (1987) there is not an overall preferred margin of safety. Another alternative is that they were attempting to return to a preferred margin of safety but it took some time to become accustomed to the simulation. The participants may have been less safe initially due to differences in the information provided by the simulation compared to the real world, such reduced peripheral vision and the lack of stereoscopic differences. There was a significant increase in safety ratio once the brace was removed which seems to come primarily from the difference at the 60-m initial distance. Whereas there is a difference at the other two levels the difference at 60 m is about three times larger. This may be related to the discrepancy noted earlier (the 50-m distance was associated with the lowest safety ratio for Block 10), and may also indicate that it was the 60-m level that was safer than expected, not the 50-m level being less safe, that caused the trend in Blocks 1, 2, and 10. The overall difference is likely to be due in part to the increase in walking speed once the brace was removed. It may also be related to an attunement with the impaired walking speed, as is likely the case with the difference between the first and last impaired blocks. If the participants were attuned to the impaired speed they may have been favouring gaps that were suitable for their reduced speed. Even though their speed was increased by the removal of the brace they still selected larger gaps, 2.74 s compared to 2.62 s (the overall average for the impaired trials was 2.73 s), although the differences are only slight.

The decrease in safety ratio when the brace was attached and the increase after it was removed were of a similar magnitude (13% and 15% respectively). This may also indicate attunement to the earlier walking speed, the change in walking speed resulting in a similar change in safety ratio. This will also require further experimentation, although it may be feasible to combine this with an experiment investigating a preferred margin of safety. In any case, more participants and possibly more blocks of trials will be required to determine if the effect is robust.

There is a relationship between walking speed and safety ratio since the participant's time-to-cross was used in calculations for both. However, unlike in the forced-choice crossing case (Owen et al., 2002), walking speed does not seem to be the single variable affecting safety. This is indicated in part by the slight differences in trend over the eight impaired blocks (see Figures

12 and 15). While the initial dip in walking speed is matched by a decrease in the safety ratio, at Block 8 walking speed is still decreasing whereas the safety ratio is increasing. However, at the same block the gap percentage used is increasing. This suggests that both a participant's walking speed and the amount of the gap they use affect safety. They also appear to do so independently as there were no significant relationships between the two. This makes sense as there is no overlap in the measurement of these variables. The percentage of the gap used is calculated using the T_a of the van once the participant has moved 0.5 m, whereas the walking speed is measured from 0.5 m to the far edge of the van, approximately 3 m from the starting point. Walking speed may affect overall changes in safety ratio, such as the changes related to the leg brace, whereas the percentage of the available gap used may relate to specific changes based on distance information. Decreasing the participants' walking speeds did not change the distance effect as indicated by the lack of any interactions, but rather shifted it down; the same effect profile but with lower safety ratios. This explanation is supported by the lack of distance effects for walking speed and the lack of mobility condition effects for the percentage of the gap used, whereas both effects occur for the safety ratio. Overall, the higher the walking speed and the greater the percentage of the gap used the safer the crossing, which makes intuitive sense.

4.3.2 General Discussion

Participants were willing to walk significantly faster in the virtual environment experimental trials than when rushing in the actual environment. This suggests that they are immersed in the simulation. This result also supports previous analyses indicating that people are willing to walk at least as fast in the experimental trials as they rushed in the actual environment (Owen et al., 2002; Simpson, 2002).

Support for the efficacy of the simulation also comes from cautious crossings. Although participants were instructed to cross in a gap, 13 did not feel safe crossing in any of the gaps available during some of the trials. The participant who only crossed cautiously commented that, due to previous aversive experiences crossing roads, she did not feel safe crossing while there were vans approaching. She also commented that she had difficulty judging the distance of vehicles at night when there are only the headlights to use for information. According to theories of optical expansion (e.g. Lee, 1976; Lee & Reddish, 1981; McLeod & Ross, 1983) this should provide enough information to judge time-to-arrival information, so it is possible that the participant may have difficulty using this information. This case will be discussed further in Section 4.3.6.2.

The commercial leg brace was superior to the custom brace in reducing mobility. While there was very little difference in the walking speeds between the two mobility conditions in Experiment 1, the brace significantly reduced walking speed in Experiment 2 by 0.2 m/s on average. This is equivalent to another 0.5 s on the road (0.2 times the 2.5-m width of road walking speed was measured over). Since the cut off-for an unsafe crossing was 0.5 s this decrease was enough to turn a safe crossing into an unsafe one, or a near miss into a collision.

The increase in walking speed over the impaired trials was expected based on prior research. For Owen et al. (2002) walking speed kept increasing across the 27 experimental trials. Familiarity with the simulation and a lack of negative interactions with the actual environment may be the reasons for the increase. For this experiment it would seem likely that increasing familiarity, both with the virtual environment and with the leg brace, would account for this increase in the impaired walking speed. Walking speed appeared to increase until Block 5 after which it decreased slightly, perhaps a sign of fatigue, until an increase between Blocks 8 and 9. The increase may have been due to participants being aware that the leg brace was going to be removed (they were informed that there would be 60 trials and the trial number was presented before the beginning of each trial), although it is uncertain why this would affect their speed. It may also been random variation as the decrease and subsequent increase are fairly small, around 0.02 m/s, and this is supported by examining the two sets (see Appendix F) as a decrease in speed over one set is not necessarily replicated for the other.

The end of Block 5 is equivalent to 30 trials, suggesting that up to this point there have not been enough trials to detect an asymptote in walking speed. The impaired walking speed did not return to the unimpaired speed, as indicated by the significant difference in speeds when the leg brace was removed, so even when the participants were accustomed to walking with the brace on it still impaired their movement.

One interesting result was the lack of a difference between the first and last impaired blocks. If it was solely familiarity with the virtual environment that produced the increase in walking speed there should also be an increase in the unimpaired walking speed. It is possible that there was some residual impairment from the leg brace. Having the leg immobilised for around 20-25 min may have left the leg temporarily less mobile, and some participants commented that their leg felt strange when the brace was removed. Participants may have also become attuned to their impaired walking speed meaning that their original walking speed may have felt like it was faster than it actually was.

There was only a main effect of initial distance, and no effect of mobility condition for the percentage of the available gap used and gap number chosen. It is surprising that there was no main effect of distance for walking speed except over the eight impaired blocks. In the previous forced-choice studies (Owen et al., 2002; Simpson et al., In Press; Simpson & Owen, 2002) there were effects on walking speed attributable to distance. This indicates a difference between the two types of situations simulated; for the forced-choice crossing people walk faster when the distance is shorter whereas for the gap-choice crossing distance affects how long they wait before crossing in front of a specific van, waiting for less time when the distance is shorter.

The effect of the initial distance between vans on both the percentage of the gap used and the gap number chosen are quite straightforward. In both cases the effect indicates that the participants are attending to the irrelevant distance information, as predicted. There is a difference however. The significant interaction between Blocks 2 though 9 and initial distance between vans for gap number chosen indicates that, over blocks, the participants are tending towards choosing a specific gap, approximately the same as the gap chosen for the 50-m initial distance, regardless of the initial distance. This is similar to the trend noted in Experiment 1 (see Figure 7). This is interesting as it suggests that the participant's attention to distance information decreases when deciding when to cross but not when deciding how long to wait until crossing. Although this is quite feasible, as knowing which gap someone chose provides no information about how much of the gap they utilised (evidenced by the general lack of a relationship between the two variables), it is an odd result nonetheless. It should also be noted that although this trend occurred for the percentage of the available gap chosen and the safety ratio in Experiment 1 it did not occur in Experiment 2, suggesting it may not be robust. In Experiment 1, although this trend was evident for the random trials it did not occur for the increasing trials. While the gap chosen converged for the random trials it diverged for the increasing trials. This indicates that the participants were not just crossing after a set number of vans had passed, regardless of the initial distance between them. If they had, the same trend would have occurred for both types of trial. Why differences in trends occurred is not certain.

In Experiment 2 the gap number chosen is interesting in that it is the only variable from which an estimate of safety cannot be derived, since the gaps were randomised within a trial. In contrast, for an increasing trial (Experiment 1) it is informative as the gap number relates to a specific gap size. It was also the only variable to have a consistent effect in relation to measures of risk taking (the RTQ and cautious versus non-cautious participants). Although disappointing overall, the only significant correlations between the scales of the RTQ and the dependent variables occurred with gap number chosen. The ad-hoc cautious versus non-cautious analysis produced better results, showing significant relationships with all bar one of the block means for gap number chosen as well as showing a relationship with the overall mean gap chosen. Although the non-cautious participants tended to be safer overall, these differences were only slight but they may indicate that the cautious participants were *aware* they should be cautious. It may be the case that the gap number chosen indexes impulsivity, an explanation supported by the result that the non-cautious participants consistently crossed sooner than the cautious ones.

4.3.3 The Risk Taking Questionnaire

Although there has been some success using the RTQ (Owen et al., 2002), it requires further development. It has only been administered to small samples so far (35 from this experiment and 23 from Owen et al (2002)). To reduce the size of the questionnaire, which is desirable as it takes between 10 and 15 minutes on average to complete, a larger sample is required. This may occur in two ways. The first is to administer the RTQ to a large number of participants, perhaps a sample of first-year psychology students, in order to reduce the number of activities. Using a larger sample a principle components analysis can be conducted. This should indicate which activities discriminate most between high and low risk-takers allowing the less discriminating activities to be removed. The second is to test a larger number of participants in the road-crossing simulation, such as 100 participants, to see which activities and scales relate to performance measures. It is likely that both options will be used as both will advance the development of the questionnaire. Further validation can come from comparing scores on the RTQ to scores on other standardised instruments.

4.3.4 Implications

In general the safety ratio decreased when the brace was attached, although this was not matched by an equivalent increase in unsafe crossings there was a slight decrease when the brace was removed. The decrease in mobility may be more important for those people already predisposed towards accidents as a decrease in walking speed is unimportant if the gap chosen still affords safe crossing. If these people can be identified in advance it would be useful to be able to instruct them in regards to crossing safety. The increase in walking speed and safety ratio implies that practise improves a person's ability to move while impaired. The person may become used to their new walking speed, and use this speed, rather than their original walking speed, when judging the safety of a gap. This may counteract the initial decrease in safety. If the person is given time to practise walking while impaired the decrease in safety may never be evidenced. It is possible however that the improvement came solely from the participant becoming accustomed to walking in the virtual environment. Although this may account for some of the improvement, the lack of a difference between the two unimpaired blocks suggests that it does not account for all of the improvement over the impaired blocks.

The effect of distance is evident in the last blocks suggesting that the participants were still attending to this irrelevant information. Although it can be useful in areas where the speed of the traffic is relatively constant, it would be better to train people to attend to T_a information. Even if the traffic speed is constant, occasionally there may be vehicles travelling significantly faster than that and these situations may be a cause of accidents. Connelly et al. (1998) noted that in a 50 km/h zone speeds ranged from 26 km/h to 78 km/h, with 39% of the vehicles exceeding the posted speed limit by 6 km/h or more. In this situation reliance on distance information could well prove hazardous. Being able to determine the people most at risk would enable the training to be focused on them rather than safer crossers. Identifying those most at risk in both of these situations (mobility impairment and attention to distance information) will require further experimentation, especially in regards to identifying any personality traits that may indicate increased risk.

Those participants who did not have any cautious crossings were marginally safer than those who had at least one. This suggests that the cautious people knew they should be cautious. This can be investigated in any future experiments. In each experiment using VR so far some participants have crossed cautiously so it is expected that this trend will continue. Comparisons can be made between the cautious and non-cautious groups to ascertain if this is a robust effect. This may be one method of identifying people who are most at risk. There was a relationship between how many activities a participant was willing to do and whether they crossed cautiously or not, so the RTQ may be able to help predict these who these people are.

4.3.5 Limitations

The information available in the simulation does not fully match that available in the real-world crossing situation. This is most noticeable in the field of view afforded by the HMD, 48 degrees compared to approximately 180 degrees in the real world. Participants had to look at either the van or the street light when crossing whereas in the real world we can look at one and have the other in our peripheral vision. Some of the participants commented that to walk in a straight line across the road they could not look at the vans. There may also be other sources of information that are used in making road-crossing decisions, such as eye contact with the driver. This information could be included in a distributed interactive simulation with both driver and pedestrian as participants. Presenting the same image to each eye removes parallax as source of information for distance, which may have affected the performance of the participants. Although attention to distance information was not desirable, this may result in reduced immersion in the simulation. The information available in the simulation does not fully match the information available in the actual task.

There were a number of other unexpected technical issues that may have caused some problems. The major indication participants had that they had been hit was seeing a flicker across the screen as the van passed through their position. In some cases when they passed below the cable attached to the transmitter, the screen would jump and this may have been misinterpreted as a collision. This problem has been resolved for future experiments as there will be audio feedback for collisions (the sound of breaking glass) and close calls (a car horn). For most of the participants there was instability in the visual image for the first block of trials (the image would roll like a ship or jump fairly quickly) and this may have affected judgements for the first block of trials. It seems to be due to the equipment warming up as when the equipment was left running between participants there was less of a problem, and there was very little instability when the participants were close to the transmitter. This instability at the beginning of the experiment may have adversely affected the participants' performance. The scores on the SSQ were higher than are desirable as indicated by (Kennedy et al., 1993), the total score being between the 85th and 90th percentiles for the calibration sample. The highest score recorded was for disorientation, between the 90th and 95th percentiles.

Occasionally at the end of a trial the message to return to the starting point did not play. This may have reduced the participants faith in the simulation, and possibly to take it less seriously. The vans were also intended to disappear when the participant crossed to the centre of the road. This in itself may have caused some difficulties as, in the real world, vans do not just disappear. It was expected that the participant would generally be facing towards the street light, however, and would not see them disappear. For trials where the message was not delivered the vans did not disappear. This was noted with concern by some of the participants, particularly when there was a van blocking the path to the tree. Although this may have also reduced the efficacy of the simulation, it should also be noted that when this later situation occurred the participants were hesitant in walking through the van. There was generally not enough cable length (from the HMD) to walk around the van and so they had to walk through it, which was often described as an unusual experience. The implication is that although the behaviour of the vans was not usual for the real world, there was enough belief in the simulation to lead the participants to feel that they could not walk through the van (this was also noted in Experiment 1). Both of these problems seemed to occur when the participant passed beyond the centre line of the road fairly quickly. Consultation with the original programmer did not result in any solid reasons as to why these problems occurred. In the future careful note will be taken of these trials in an attempt to correct the problems.

One issue also arose from the randomisation of the trials. To ensure that pairs of vans were equal distance apart, velocity varied. In some cases, again only occasionally, a faster van would pass through a slower van. This was an unintended and unrealistic source of information as the overtaking van could easily be seen to be faster than the following van (i.e. have a shorter T_a). Some of the participants commented on this, although a number also attempted to cross in front of the overtaking van, suggesting that although the information was available it was not necessarily used.

4.3.6 Design Extensions and Future Research

Power across both experiments varied considerably, from almost no power to 100% power. The initial distance between vans was associated with the greatest power in Experiment 1 (see Appendix F), and was generally high in Experiment 2, although it varied across the individual analyses for each dependent variable (see Appendix G). The power for type of trial (Experiment 1) and mobility condition (both experiments) was low, 80% power being achieved in only two analyses for Experiment 2 (the walking speed comparisons between Block 1 and Block 2, and Block 9 and Block 10). This indicates that future research will require larger sample sizes to achieve sufficient power for effects other than for the initial distance between vans.

4.3.6.1 General Extensions

Future research may focus on some of the issues arising from this experiment. For instance, whether or not there is a constant change in safety when the mobility condition is changed, either being impaired or unimpaired, could be investigated. This may involve using alternating blocks of unimpaired and impaired trials, such as one block of unimpaired, four blocks impaired, four blocks unimpaired, one block impaired. If there is a fairly constant change then it should be evident in each case (four blocks were chosen as this seems to be the point at which the participants walking speeds began to reach an asymptote). This would also have an advantage in that it may indicate whether the trend in safety ratio at the 50-m initial distance when conditions change is robust.

Different age groups may also be investigated. There may be age related differences in road-crossing behaviours, or there may be personality factors that are better predictors of performance. Zuckerman and Kuhlman (2000) found that sex differences were moderated by a personality factor, impulsive sensation seeking. There may be a similar effect for age differences. A slower walking older person may be taking as great a risk as a faster younger person, but a direct comparison of their gap choices may incorrectly suggest that the younger person is taking greater risks (e.g. Harrell & Bereska, 1992). The RTQ may be useful in identifying whether any differences in age groups are better explained by risk-taking.

One of the end goals for this program of research is combining the road-crossing and recently developed driving simulation. The current simulation involves a real person and computer controlled vehicles. Although this is useful for producing consistency across the conditions, it reduces the ecological validity as the behaviour of the vehicle does not change, whereas in the real world drivers tend to modify their behaviour when they see a pedestrian. Interactions between two participants may be used to model computer controlled vehicles or pedestrians in future research.

4.3.6.2 Virtual Reality as a Training Aid

Virtual reality has been used as a training aid in such areas as autism (Strickland, Marcus, Mesibov, & Hogan, 1996), as well as pedestrian safety using desktop VR (McComas, MacKay, & Pivik, 2002). It is hoped that VR may be useful training people who are at an increased risk of having an accident, e.g. those who rely on distance information. Initial performance measures, as well as post-training performance measures, will be taken using random trials. The actual training would use increasing trials. Participants will be instructed to cross after a specific number of vans, at least 5, have passed and that this will always be safe given the individual's walking speed. The actual number will be determined by pilot testing to ensure safety on every trial. A wider range of initial distances will also be used, perhaps adding 30-m and 70-m levels. If the training is successful there should be few, if any, effects of initial distance evident in the post-training data.

It will also be necessary to investigate the effect of distance using the increasing trials. The effect noted for gap number chosen in Experiment 1 (Sections 3.3.4; see Figure 7), in which over time there was divergence in the regression lines for the distances for the increasing trials but convergence in the random trials, was repeated with the random trials used in Experiment 2 (Section 4.2.5.1; Figure 20). This suggests that the effect on the random trials is robust.

Although the same effect was noted for the safety ratio and the percentage of the gap used in Experiment 1 (Section 3.3.6) the same effect was not repeated in Experiment 2. If the effect is only robust for the gap number chosen it should not cause too many problems for training. Which gap number they choose is not as important as how large the gap is. Ideally though the gap number chosen would not exhibit any distance effect after training.

The next stage will involve examining the effects of training on real-world behaviour. McComas et al (2002) put coloured tags on the backpacks of children participating in their desktop VR training program. The tags indicated which condition the child was in (treatment or control) as well as grade. Performance was measured in the following fashion:

> Children were observed for the following four behaviours: (1) walking on the sidewalk versus walking on the street; (2) stopping at the curb; (3) looking L-R-L before crossing; and (4) staying attentive while crossing the street. For each correct action they were given one point (p. 187).

This method may be modified for adult participants. One potential confound would be if the participants altered their crossing behaviours since they are being observed. If this occurs hopefully it would be consistent between pre- and post-training sessions; if so improvement would still be evident.

An examination of the efficacy of the VR simulation as a training aid may be conducted using the participant who only crossed cautiously, depending on their availability (the individual is willing to participate but may be leaving the city). As they appear to have difficulty attending to

T_a information training may be useful for them, although some care must be taken as how learning in the road-crossing transfers to the real world is not yet known.

4.3.7 Conclusions

Although the safety ratio decreased when the brace was attached, participants adapted to their impaired walking speed fairly quickly resulting in an increase in the ratio. The increase in safety can also be attributed to participants using more of the available gap across blocks.

Irrelevant distance information was used in making road-crossing decisions, with the participants using more of the gap when the vans were initially closer, and also waiting longer before crossing when the vans were closer as shown by the gap number chosen. While distance information may be informative if the vehicles are travelling at relatively similar speeds, when this is not the case, distance information is misinformative in regards to gap choice. Since a greater percentage of unsafe crossings occurred when the initial distance between vans was greater this is potentially hazardous.

Very few firm conclusions can be drawn from the analysis of risk-taking, using either the self-report RTQ or the post-hoc cautious crossers comparison. Those participants who were higher in risk taking, or who had no cautious crossings, tended to walk slightly faster than the other participants, and also crossed sooner as indexed by the gap number chosen. Those participants with higher risk-taking scores generally seemed safer than those who scored lower, but replication with a larger sample size is needed to confirm if this effect is robust.

5. References

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6 Appendices

6.1 Appendix A: Simulator Sickness Questionnaire

Please indicate how much each symptom is affecting you ***right now***.

General Discomfort	*None*	*Slight*	*Moderate*	*Severe*
Fatigue	*None*	*Slight*	*Moderate*	*Severe*
Headache	*None*	*Slight*	*Moderate*	*Severe*
Eyestrain	*None*	*Slight*	*Moderate*	*Severe*
Difficulty focusing	*None*	*Slight*	*Moderate*	*Severe*
Increased salivation	*None*	*Slight*	*Moderate*	*Severe*
Sweating	*None*	*Slight*	*Moderate*	*Severe*
Nausea	*None*	*Slight*	*Moderate*	*Severe*
Difficulty concentrating	*None*	*Slight*	*Moderate*	*Severe*
Fullness of head[1]	*None*	*Slight*	*Moderate*	*Severe*
Blurred vision	*None*	*Slight*	*Moderate*	*Severe*
Dizzy (eyes open)	*None*	*Slight*	*Moderate*	*Severe*
Dizzy (eye closed)	*None*	*Slight*	*Moderate*	*Severe*
Vertigo[2]	*None*	*Slight*	*Moderate*	*Severe*
Stomach awareness	*None*	*Slight*	*Moderate*	*Severe*
Burping	*None*	*Slight*	*Moderate*	*Severe*

[1]Fullness of head refers to an awareness of pressure within the head.
[2]Vertigo refers to a loss of orientation with respect to vertical or upright

6.2 Appendix B: Risk-Taking Questionnaire (RTQ)

Instructions

For each activity please tick the one box out of the first three boxes that most applies to you now (Would not do, May consider doing, Would do). After this fill in the number of times you have done this activity, and how risky you perceive it to be. This means that you can be unwilling to repeat an activity having done it previously; hence you may tick "would not do" as well as putting '1' under "have done".

For the questions at the end please answer as accurately as possible. If there are multiple options please circle the most appropriate answer. If there are spaces please fill in the numbers if you know them. All answers will remain confidential and will not be linked to your name.

Thank you for taking the time to help with this experiment.

Information Age:__________

Circle those that apply:
Sex: Male Female
Average time each day spent using a computer: _________________
Average time each day spent playing computer games: _________________

Glossary

River Surfing: Travelling down a river lying on a specially designed board

Sky Scraper Viewing Platform: A viewing platform that looks over the edge of a sky- scraper. Also includes glass floors, such as the one in the Sky Tower that is over the edge of the building.

Girder Crossing: A guided tour over the walkways on a harbour bridge, such as Auckland or Sydney Harbour Bridges.

Abseiling: Walking backwards down a vertical surface using ropes.

Rap jumping: Walking forwards down a vertical surface using ropes.

Activity	Would not do	May consider doing	Would do	Have done (insert number of times)	How risky is this activity? Low (1-10) high
White water rafting					
White water kayaking					
Sea kayaking					
Jet boating (passenger)					
Jet boating (driver)					
Surfing					
Wind surfing					
River surfing					
Diving/ snorkelling (shallow waters)					
Shark cage diving					
Guided shark diving at feeding time					
Looking over the edge of a sky scraper viewing platform					
Girder crossing on a harbour bridge					
Hang-gliding (tandem with instructor)					
Hang-gliding (alone)					
Sky-diving (tandem with instructor)					
Sky-diving (alone)					
Abseiling down a vertical surface					
Rap jumping down a vertical surface					
Bungy jumping					

Mountaineering					
Tramping (established track)					
Caving (guided)					
Climbing Mount Taranaki					
Climbing Mount Cook (guided)					
Climbing Mount Everest (guided)					
Horse trekking					
Cycle touring					
Mountain biking					
Downhill cycle riding (streets)					
Bicycle riding (transport)					
Motorcycle riding (passenger)					
Motorcycle riding (driver)					
Car driving (general city transport)					
Go-cart driving					
Skate boarding (transport)					
Inline skating (transport)					
Helicopter flights					
Scenic flights (small aeroplane)					
Hot air ballooning (passenger)					
Skiing (controlled fields)					
Snow boarding (controlled fields)					
Luge (wheeled, not ice)					

Flying fox (fun, not transport)					
Playing contact sports					
Playing non-contact sports					
Running with the bulls in Spain					
Burnham Assault Course					
Snake Handling					

Circle those that apply:

Highest diving board used: Do not use 1 meter 3 meter 10 meter

Do you use a seatbelt while driving? Never Sometimes Always

Do you use a cell phone while driving? Never Sometimes Often

Have you had any tickets for speeding? Yes No
How many? __________ How much over the limit? __________km/h

Have you ever driven under the influence of a legal drug that may cause drowsiness? Yes No

Have you ever driven under the influence of an illegal drug? Yes No

Have you ever driven under the influence of alcohol? Yes No
How much over? __________

Have you had any citations for driving under the influence? Yes No
How many? _________

Are there any activities that you have done that are not listed? Please write them below.
____
____
____
____

Are there any other activities not listed that you feel should be listed? Please write them below.
____
____
____
____

6.3 Appendix C: INFORMATION SHEET

Mobility Impairment Road Crossing Study

You are invited to participate in an experiment that forms part of a wider program of research investigating human performance in virtual environments. The project is being carried out by Stephen Murray under the supervision of Dr Dean Owen, who can be contacted on extension 6166. He will be pleased to discuss any concerns you may have about participation in the project. In this experiment, I am interested in studying how mobility impairment affects the safety of an individual's road crossing behaviour. Therefore, the following experiment consists of a road crossing simulation in which you will cross a virtual road.

Note: Some virtual reality users experience a condition known as *simulator sickness* which is somewhat similar to motion sickness. Symptoms are variable but may include general discomfort, fatigue, headaches, dizziness, eyestrain or nausea. If you experience mild discomfort please attempt to continue. If you feel you are unable to continue then please let me know and I will stop the experiment immediately. If you feel unable to travel on your own an alternative form of transport will be arranged, at my expense.

It is understood that by signing the attached consent form you have agreed to participate in this project and assented to publication of the findings. You are assured that in any such publication your anonymity will be preserved. It is also understood that you may withdraw from the experiment at any time, including the withdrawal of any information you have provided.

This research has been reviewed by the University of Canterbury Human Ethics Committee.

6.4 Appendix D: Road Crossing Instructions

You are about to take part in a road crossing simulation. You will wear a virtual reality helmet that displays a straight, flat stretch of road and traffic. You can look around by turning your head and move by walking. You may withdraw from the experiment at any stage.

Before the experimental trials there will be 8 practice trials. The first 2 will be in the actual laboratory environment. You will be asked to walk at a normal walking speed and then walk as if you are in a rush. The next 6 trials are in the virtual environment to familiarize you with walking in that environment. For the first 3 of these you will be asked to walk at a normal walking speed and the last 3 walk as if you are in a rush. There will be no traffic in the virtual environment practice trials. You will walk towards a street light. When you have crossed the first lane to the centre of the road, you will hear a verbal instruction to turn around and return to your starting position. It is important that once you begin walking towards the street light, **keep walking until you hear the instruction to turn around**. Do not stop walking until you hear the instruction. At this point you should turn completely around to your right and walk back across the road towards the tree that you will see in front of you.

In the following experimental trials there will be a line of 11 vehicles approaching from your right creating 10 gaps of different size. At the beginning of each trial turn to your head to the right to observe the approaching vehicles. Your task is to choose a safe gap to cross to the center of the road. At the end of each trial you will hear an instruction to turn around and return to the start. You may walk back to the tree at a speed that is comfortable to you. There will be no traffic on the way back.

For the first block of trials you will be unimpaired. For the following blocks of trials, except the final block, you will be wearing a knee brace. For the final block you will again be unimpaired.

It is important that you **keep walking until you hear the instruction to turn around.** If you think you have been hit by a van continue walking until you hear the instruction to turn around.

6.5 Appendix E: CONSENT FORM

Mobility Impairment Road Crossing Study

I have read and understood the description of the above named project. On this basis I agree to participate as a subject in the project, and I consent to the publication of the results of the project with the understanding that anonymity will be preserved. I understood also that I may at any time withdraw from the project, including withdrawal of any information I have provided.

Signed ……………………………………
Date ……………………………………

6.6 **Appendix F**: Effect Sizes and Power Analyses for Experiment 1.

Table 8. The effect sizes (Cohen's *d* for mobility condition, and f^2 for distance and type of trial) and power analyses for Experiment 1.

Safety Ratio	**effect size**	**power**
Mobility Condition	0.01	0.05
Distance	11.38	1.00
Type of Trial	0.07	0.20

Walking Speed	**effect size**	**power**
Mobility Condition	0.43	0.15
Distance	0.00	0.05
Type of Trial	0.12	0.30

Percentage of Gap Used	**effect size**	**power**
Mobility Condition	0.21	0.07
Distance	27.30	1.00
Type of Trial	0.63	0.91

Gap Number Chosen	**effect size**	**power**
Mobility Condition	0.23	0.08
Distance	9.11	1.00
Type of Trial	3.43	1.00

6.7 **Appendix G**: Effect Sizes and Power Analyses for Experiment 2.

Table 9. Effect sizes (f^2) and power analysis for Experiment 2. A dashed line indicates negligible power.

Safety Ratio	**Effect**	**effect size**	**power**
Block 1 to Block 2	Mobility Condition	0.022	0.13
	Initial Distance	0.024	0.11
Block 9 to Block 10	Mobility Condition	0.074	0.33
	Initial Distance	0.010	0.07
Block 1 to Block 10	Block	0.170	0.63
	Initial Distance	0.002	0.05
Blocks 2 through 9	Block	0.084	0.18
	Initial Distance	0.863	1.00

Unsafe Crossings	**Effect**	**effect size**	**power**
Block 1 to Block 2	Mobility Condition	0.000	-
	Initial Distance	0.018	0.09
Block 9 to Block 10	Mobility Condition	0.009	0.08
	Initial Distance	0.003	0.06
Block 1 to Block 10	Block	0.246	0.79
	Initial Distance	0.002	0.05
Blocks 2 through 9	Block	0.014	0.07
	Initial Distance	0.453	0.93

Walking Speed	**Effect**	**effect size**	**power**
Block 1 to Block 2	Mobility Condition	0.733	1.00
	Initial Distance	0.001	0.05
Block 9 to Block 10	Mobility Condition	0.252	0.80
	Initial Distance	0.001	0.05
Block 1 to Block 10	Block	0.000	0.05
	Initial Distance	0.001	0.05
Blocks 2 through 9	Block	0.014	0.07
	Initial Distance	0.024	0.11

Percentage of Gap Used	Effect	effect size	power
Block 1 to Block 2	Mobility Condition	0.000	-
	Initial Distance	0.166	0.52
Block 9 to Block 10	Mobility Condition	0.001	0.05
	Initial Distance	0.254	0.72
Block 1 to Block 10	Block	0.780	1.00
	Initial Distance	0.204	0.62
Blocks 2 through 9	Block	0.285	0.57
	Initial Distance	2.215	1.00

Gap Number Chosen	Effect	effect size	power
Block 1 to Block 2	Mobility Condition	0.000	-
	Initial Distance	0.866	1.00
Block 9 to Block 10	Mobility Condition	0.145	0.56
	Initial Distance	0.505	0.96
Block 1 to Block 10	Block	0.067	0.30
	Initial Distance	0.514	0.96
Blocks 2 through 9	Block	0.011	0.06
	Initial Distance	3.427	1.00

6.8 **Appendix H:** Correlations Between the Dependent Variables for Experiment 2

Table 10. The correlations between the dependent variables for Experiment 2. Significant correlations, p<.0045, are highlighted in grey.

Mean	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.58			
Unsafe Crossings	-0.78	-0.27		
Gap Number Chosen	-0.29	-0.23	0.11	
Percentage of the Gap Used	0.55	0.29	-0.49	-0.34

Block 1	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.12			
Unsafe Crossings	-0.70	0.29		
Gap Number Chosen	-0.22	-0.12	0.24	
Percentage of the Gap Used	0.62	0.21	-0.33	-0.17

Block 2	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.45			
Unsafe Crossings	-0.80	-0.17		
Gap Number Chosen	-0.23	-0.24	0.14	
Percentage of the Gap Used	0.66	0.40	-0.58	-0.16

Block 3	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.40			
Unsafe Crossings	-0.84	-0.10		
Gap Number Chosen	-0.04	-0.05	0.12	
Percentage of the Gap Used	0.64	0.17	-0.59	-0.06

Block 4	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.53			
Unsafe Crossings	-0.62	-0.30		
Gap Number Chosen	-0.17	-0.15	-0.37	
Percentage of the Gap Used	0.56	0.24	-0.34	-0.35

Block 5	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.56			
Unsafe Crossings	-0.68	-0.14		
Gap Number Chosen	-0.10	-0.17	-0.11	
Percentage of the Gap Used	0.62	0.26	-0.72	-0.08

Block 6	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.51			
Unsafe Crossings	-0.80	-0.21		
Gap Number Chosen	0.00	-0.08	-0.05	
Percentage of the Gap Used	0.60	0.20	-0.60	-0.29

Block 7	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.37			
Unsafe Crossings	-0.65	0.03		
Gap Number Chosen	-0.26	-0.15	0.15	
Percentage of the Gap Used	0.57	0.17	-0.52	-0.37

Block 8	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.43			
Unsafe Crossings	-0.67	-0.21		
Gap Number Chosen	-0.08	-0.15	0.22	
Percentage of the Gap Used	0.40	0.03	-0.34	-0.19

Block 9	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.56			
Unsafe Crossings	-0.64	-0.01		
Gap Number Chosen	-0.29	-0.33	-0.12	
Percentage of the Gap Used	0.46	0.14	-0.20	-0.36

Block 10	Safety Ratio	Walking Speed	Unsafe Crossings	Gap Number Chosen
Walking Speed	0.64			
Unsafe Crossings	-0.64	-0.16		
Gap Number Chosen	-0.49	-0.28	0.33	
Percentage of the Gap Used	0.37	0.18	-0.39	-0.53

6.9 **Appendix I:** Glossary of Abbreviations

HMD: Head Mounted Display

RTQ: Risk-Taking Questionnaire

SSQ: Simulation Sickness Questionnaire

T_a: Time-to-Arrival

VR: Virtual Reality